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Performance and within-hybrid variability of three-way and single-crosses in grain sorghum, Sorghum bicolor (L) Moench

Edward Joseph Walsh
Iowa State University

Performance and within-hybrid variability of three-way and single-crosses in grain sorghum, Sorghum bicolor (L.) Moench

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Edward Joseph Walsh

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INTRODUCTION

In 1954 cytoplasmic male sterility in sorghums, resulting from an interaction between milo cytoplasm and kafir nuclear factors, was reported by Stephens and Holland (1954). This discovery made possible the large scale production of sorghum hybrids. The hybrids have distinct advantages over pure line varieties, particularly in yield, and in relatively short time virtually the entire grain sorghum acreage in the United States was planted with hybrid seed.

The conventional method of producing hybrid seed involves growing a male-sterile, or A-line, in a seed producing block, that also contains a pollinator line carrying fertility restoring genes in the homozygous condition. The pollinator line generally is called an R-line. To maintain the male-sterile line, it is grown in an isolated field with its fertile counterpart, commonly called a B-line. The B-line is identical to the A-line except that it has normal cytoplasm, and unlike the R-line in the seed producing block, it does not carry fertility restoring genes.

At present nearly all sorghum hybrids are produced in this manner. The object of this study was to evaluate the performance of hybrids produced by a somewhat different system. These hybrids are three-way crosses that involve three distinct genotypes.

In the production of three-way hybrids the A-line is

maintained in the usual way by crossing with its fertile non-restoring counterpart, but the A-line is then crossed with a B-line other than its counterpart. This sterile F_1 hybrid is then crossed with an R-line to produce seed of a fertile three-way hybrid.

An evaluation of the performance of three-way hybrids seemed desirable for several reasons. Heterosis should be expressed in the sterile single-cross thereby reducing land requirements for hybrid seed production and lowering, or at least stabilizing, the cost of hybrid seed. Also, hybrid seed produced on vigorous F_1 plants might have an initial advantage in seed or seedling stages over seed produced on less vigorous inbred plants.

Three-way hybrids might also have an advantage in stability of performance under different environmental conditions. The greater stability may result from either "individual" or "populational" buffering. Individual buffering refers to the ability of a particular genotype to perform equally well over a range of environments. This type of stability is plant oriented. Populational buffering, on the other hand, refers to stability of performance resulting from the heterogeneous nature of the population. Although individual buffering may be as much a feature of single-cross hybrids as it is of three-way crosses, populational buffering is precluded in single-crosses.

The ability of a hybrid to give high yields in different

environments has obvious advantages. Variability within the hybrid may lead to stability of production, but gross variability for plant height, maturity and other morphological characters would be a distinct agronomic disadvantage. My study was not conducted over sufficient environments to permit reliable conclusions relative to stability of performance. Instead, the range in variability and its relationship with the performance of single-cross and three-way hybrids in two highly productive environments were evaluated and the results are presented in this dissertation.

LITERATURE REVIEW

Relative Merits of Single-cross and Three-way Hybrids

The suggestion that three-way hybrids might have practical importance in grain sorghum production is not new. Stephens, Kuykendall and George (1952) reported the discovery of genetic male-sterility in Day Milo and proposed a method for the production of hybrid seed with a three-way cross. It is conceivable that three-way hybrids would predominate today were it not for the discovery of cytoplasmic-genic male-sterility by Stephens and Holland (1954). Also, it is of interest that some three-way hybrids were marketed during the mid-1950's. A few of the forage sorghum hybrids produced currently allegedly are three-way crosses (Ross, 1969).

The main reason why Stephens et al. (1952) proposed three-way crosses seems to have been to obtain lower production costs for hybrid seed than would be possible with single-crosses of inbred parents. Stephens and Lahr (1959) suggested that the use of hybrid, instead of line, male-steriles as seed rows in hybrid seed production should merit consideration by seed producers. Their suggestion was based on experiments conducted during two seasons which showed that the average seed production on sterile single-crosses exceeded that on line male-steriles by 71%. The greater seed yield of sterile single-crosses resulted from a higher percentage seed set. Efforts to relate this superiority of sterile hybrids to

greater stigma exposure or longer receptivity were not successful. These workers were aware, of course, that the utility of three-way crosses was dependent upon the attainment of acceptable levels of yield and variability in the farmers' fields.

The use of sterile single-crosses in hybrid seed production for short statured (3x4 dwarf) hybrids also has been suggested by Rosenow (1968). He found that seed yield of sterile single-crosses in a single year's test at Lubbock, Texas, exceeded that of their best parents by amounts ranging from 3.2 to 18.3%. All single-cross combinations, however, did not give statistically significant yield increases.

The possibility for greater seed production and yield stability over a range of environments prompted Jowett to plant a series of trials involving three-way hybrids in Uganda, East Africa, the results of which were reported by Doggett and Majisu (1966). There was no difference in mean yield between single-cross and three-way hybrids, the mean yields being 2526 and 2523 pounds per acre, respectively. A comparison of the place x hybrid-type mean squares did indicate some difference in yield stability. The difference was not great, however, as shown by the mean coefficients of variation (55.8 for single-crosses and 50.2 for three-way crosses). Jowett concluded that although the advantages for three-way crosses were not great they did deserve further study.

The hypothesis that limited genetic diversity might

prove advantageous for grain sorghum hybrids grown in areas having erratic weather has been tested by Ross (1961). He grew five hybrids singly and in 1:1 mixtures under dryland conditions in Kansas during 1959 and 1960. Two-hybrid mixtures did not yield any more than the pure stand of the highest yielding component of the mixture. He concluded that the variability manifested by mixtures of two hybrids might not be sufficient to provide any advantage and he suggested the use of three-way crosses as an alternative for attaining a desirable level of genetic variability.

Stephens and Lahr (1959) evaluated three-way and single-cross hybrids in yield tests in Texas. Generally, the three-way crosses were not significantly different from related single-crosses. Three-way hybrids averaged about 2% higher in grain yield than the single-crosses. This study prompted Ross (1969) to compare single-crosses and three-way hybrids in a different environment not only for yield per se but also to see if there might be expressions of yield stability that would favor three-way crosses. He assumed that if advantages could be demonstrated, seedsmen might respond and supply three-way hybrids for sorghum growers. Twenty-four three-way crosses and 16 related single-crosses, involving four male-sterile and four restorer lines, were tested under dryland conditions over four years at Hays, Kansas. The female parents included Combine Kafir 60 and White Wheatland and the male parents included Caprock and Plainsman. For the

four-year period the two types of crosses did not differ in mean grain yield. When individual year yields were compared however, the two types differed significantly in two of the four years, and they differed in opposite directions in these two years. One year was characterized by low yields and under these conditions three-way crosses yielded less than the single-crosses. The reverse was true in the year characterized by high yields. Ross suggested that three-way test crosses might have utility for screening restorer lines and for certain plant breeding studies.

Differences in the yields of the two groups were attributed to the differential response of within-population segments to a particular set of environmental conditions. Time and duration of drought stress at critical points in the reproductive cycle of the plant, primarily booting, blooming and early seed development were cited as factors that might cause the differential response. In support of this contention Ross suggested that in three-way hybrid populations each reproductive stage encompasses longer time than it does in single-cross populations, e.g., blooming begins earlier and lasts longer. Should adverse conditions coincide with blooming, most plants in a single-cross may be hurt but a large portion of the plants in a three-way population may escape. However, if adverse conditions were not encountered until after most of the single-cross plants had bloomed, and the conditions lasted for several days, damage to a large portion

of the three-way cross would ensue. In both instances, differences in yield would be manifested.

In an experiment designed to detect the presence of epistasis, Liang (1971) studied a complete set of single-cross and three-way grain sorghum hybrids created from a set of six varieties. Mean yield of the three-way hybrids exceeded that of single-crosses. Single-crosses had a mean yield of 1692 grams per plot with a range of 806 to 2623, and the three-way hybrids averaged 2019 grams per plot with a range of 841 to 3092. Significant differences were not noted between sets of single-crosses and three-way crosses, but in 16 out of the 20 sets the three-way hybrids outyielded the single-crosses by amounts ranging from 0.2 to 848.1 grams per plot. An interesting feature was that in only 8 of the 20 sets was the best single-cross superior to the best three-way cross, and in 18 sets the poorest single-cross was lower yielding than the poorest three-way cross. The data were obtained from a single location and year. Also, Liang pointed out that the experiment was not very sensitive since the difference required for significance between set means, at the 5% level of probability, was 1243 grams per plot which was greater than half the overall plot mean.

Interest in three-way crosses also has been shown by breeders working with crops other than grain sorghum. From an experiment that included all possible single-cross, three-way and double-cross hybrids from a set of four maize inbreds,

Stringfield (1950) reported an average of 3.5% less yield for double-crosses than for single-cross hybrids. Average yield of the three-way crosses was equal to that of single-crosses.

In a two-year study of single-cross and three-way maize hybrids, Sprague and Thomas (1967) found that the mean yield of all single-crosses was 2.3 bushels per acre greater than the mean of all three-way crosses. Yields of individual single-crosses ranged from 77 to 148 bushels per acre. The range in yield for the three-way hybrids was only slightly less, 78 to 139 bushels per acre, with a mean of 118. The lines used in this study had not been subjected to any selection, other than natural selection, for either phenotypic characteristics or combining ability. It was suggested that the approximate equivalence in yield of the single-cross and three-way hybrids was due to the fact that any selection involved had been neutral with respect to the types of gene action affected.

Eberhart and Hallauer (1968) suggested that favorable epistatic combinations of genes in inbred lines might be important in contributing to the performance of F_1 maize hybrids. They reasoned that if favorable epistatic combinations of genes became fixed in the inbred lines during the selection process, the opportunity for recombination would not be present in the production of single-cross hybrids, thus ensuring the retention of favorable combinations. But because

of recombination in the single-cross parent used in the production of three-way hybrids, the yields of three-way crosses might be expected to be lower than those of single-crosses. However, in their investigations with maize in which significant epistatic effects had been detected there was no average superiority of single over three-way crosses. This comparison may be misleading, however, since the greater genetic variance expressed among single-crosses likely will result in one of the possible single-crosses always outyielding the best double-cross and usually the best three-way cross (Cockerham, 1961).

Weatherspoon (1970) compared yields of single, three-way and double-cross hybrids in maize. The mean yield of single-crosses was greater than that for three-way hybrids by 3.1 q/ha. Yield of the best single-cross was 8.6 q/ha above that of the best three-way hybrid, but the poorest single-cross yielded 4.1 q/ha less than the poorest three-way cross. The superiority of single-crosses was attributed to a more complete utilization of both dominant and epistatic gene effects. The hybrids x environments mean square for single-crosses was more than twice that for double-crosses, with the mean square for three-way hybrids intermediate. These results, although based on a relatively narrow range of environments, support those of previous workers (Sprague and Federer, 1951; Rojas and Sprague, 1952; Eberhart, Russell and Penny, 1964; Eberhart and Russell, 1969), indicating that

single-crosses as a group are less stable over environments than either three-way or double-crosses.

Relative Importance of General and Specific Combining Ability

Whether three-way grain sorghum hybrids will be competitive with single-crosses will depend to a large extent on relative importance within the genotypes used of the different types of gene action involved in the inheritance of grain yield and other important agronomic characters.

Sprague and Tatum (1942) originated the concepts of general and specific combining ability. They defined general combining ability as the average performance of lines in hybrid combinations. They used the term specific combining ability to designate deviations of certain crosses from the performance expected on the basis of the average performance of the lines involved. Genetically, general combining ability is associated with genes that are additive in their effects, while specific combining ability is attributed primarily to deviations from additivity caused by dominance and epistasis.

Until recently few studies on general and specific combining ability in sorghum had been conducted. King et al. (1961) and Whitehead (1962) studied the performance of sorghum hybrids and their parents in Texas and Indiana, respectively. Although variances for general and specific combining ability were not compared, these workers concluded that additive gene

action was more important than nonadditive in determining grain yield, since their results indicated that in only very few hybrid combinations was the performance substantially different from that expected on the basis of either parental performance per se, or average performance of the parents in hybrid combinations.

One hundred and ninety hybrids, produced by crossing 10 male-sterile lines with 19 fertility restoring lines, were used by Kambal and Webster (1965) in a study of the relative importance of general and specific combining ability in grain sorghum. The parents were considered a sample of those available at that time for the production of reasonably good hybrids, so that inferences could be related to other populations with which sorghum breeders were working. Characters studied included grain yield, 100-seed weight, plant height and days to first bloom. In nearly every instance, general and specific combining ability variance estimates were significantly greater than zero. General combining ability was relatively more important than specific combining ability in determining the characters studied. The ratio of σ^2_g to σ^2_s ranged from 0.7 to 18.5 with an average of 5.5.

Niehaus and Pickett (1966) computed combining ability analyses for F_1 and F_2 data from a diallel cross of eight selected inbred lines of sorghum. The traits measured included grain yield and its components, days to midbloom and plant height. In the F_1 generation all traits had significant mean

squares (0.01 level) for both general and specific combining ability. The ratio of general to specific combining ability components exceeded unity for all traits except 100-seed weight. The ratio ranged from 5.88 for plant height to 0.59 for 100-seed weight. In the F_2, the magnitude of all components was smaller, with the specific component showing a disproportionately large decrease. This indicated that there was considerable nonadditive gene action in the F_1 generation, much of which was lost in the F_2. However, since these were selected lines the observations cannot be applied to sorghum in general.

Beil and Atkins (1967) made estimates of general and specific combining ability using data from 40 F_1 grain sorghum hybrids derived from crosses between five A-lines and eight R-lines. Significant differences among general combining ability effects of the lines were obtained for grain yield and all primary components of yield, but differences among specific combining ability effects were significant only for 100-seed weight. An evaluation of variance components for grain yield revealed that variances for general combining ability were three times greater than the components for specific combining ability. Similar ratios were obtained for heads/plant and 100-seed weight. In contrast with the results of Kambal and Webster (1965) specific effects showed greater stability over environments than did general effects. Average heterosis and the mean square for parents vs hybrids also

were used as measures of nonadditive gene effects. Striking heterosis was not obtained and the parents vs hybrids mean square was not significant for any character studied, indicating the minor importance of nonadditive gene effects.

The relative importance of additive, dominance, and digenic epistasis for a number of quantitative traits in grain sorghum was investigated by Liang and Walter (1968). From the parental lines, the F_1 and F_2 generations, and backcrosses of the F_1 with each parent, of three crosses information on the nature of gene action for various traits was obtained by generation mean analyses. Additive gene effects seemed to make a minor contribution to the inheritance of grain yield, kernel weight and kernel number, but seemed more important for days to midbloom and plant height. In the inheritance of most traits, dominance effects of genes made a major contribution. Among the three types of epistatic effects, additive x additive and dominance x dominance were important. The magnitude of the additive x additive effects was comparable to that of the dominance effects and greater than that of the additive effects. Although inferences could not be made to sorghum in general the authors concluded that epistasis should not be disregarded and that genetic models assuming negligible epistasis would be biased.

Although a study of gene action was not a planned part of the experiment conducted by Ross (1969) his results did imply that epistasis was of little or no consequence for

grain yield in sorghum. This was concluded on the basis of a lack of real differences between yields of three-way and related single-cross hybrids. He suggested that the major gene effects probably were additive and dominant.

A subsequent study by Liang (1971) gave similar results. Based on the model developed by Sprague et al. (1962), the presence of epistasis was investigated by comparing the means of balanced sets of single-cross and three-way hybrids for grain yield and days to midbloom. There was no significant difference between sets of single and three-way crosses for either yield or midbloom, indicating that epistasis is not important in the inheritance of these traits. The author pointed out, however, that since the number of lines was small and not truly representative of the population with which breeders were working, valid inferences could not be made to situations involving other lines.

Variability

Because of the opportunity for segregation provided by the use of a single-cross parent, genetic heterogeneity is to be expected in three-way hybrids. This heterogeneity may be advantageous in the performance of the hybrids. Gustafsson (1946), from studies with barley, concluded that even slight genetic heterogeneity in a population can lead to effects in performance that are not simply additive properties of the components. Many workers (Burton, 1948; Allard, 1961;

Shaalan, Heyne, and Lafgren, 1966) have since investigated the possibility of improving crop performance through the use of limited genetic heterogeneity. Reich and Atkins (1970), who evaluated yield stability of four population types of grain sorghum (parental lines, F_1 hybrids, blends of parental lines, and hybrid blends) in nine environments over two years, found that heterogeneous populations (hybrid blends) were the most productive and stable population type. It is also true that an upper limit to variability is set by the demands of producers and processors of crops.

Variability within a population can arise from two sources, genetic heterogeneity and environmental variability. Variability from environmental causes can occur even in genetically homogeneous populations. Among outbreeding species of animals and plants, the nongenetic or environmental component of variability has been shown to be inversely proportional to the level of heterozygosity (Robertson and Reeve, 1952; Lerner, 1953). Working with an inbreeding species, barley, Gustafsson (1946) found that heterozygotes were more variable than homozygotes, but the difference was not great. These findings are in agreement with Lerner's (1954) hypothesis that departure from the breeding system which is normal for the species leads to reduced buffering of developmental processes in individuals, and, therefore, to greater variability resulting from differences in environment.

This hypothesis was not substantiated by later work with

inbreeding species (Jinks and Mather, 1955; Paxman, 1956; Smith and Daly, 1959) which indicated that the variability of F_1 hybrids fell within the range of the inbred parents. Working with grain sorghum, Hadley (1957) reported on the variation in plant height in two inbred parents (Double Dwarf White Sooner milo and Durra P.I. 54484) which differed widely in mean plant height and their F_1 hybrid. The shorter parent had a mean height of 17 inches with a variance of 3.1, and the taller parent (Durra) was 61 inches with a variance of 122.7. The variance for plant height in the F_1 was intermediate, 18.3, but with some indication of low variability being dominant. Hadley suggested that the greater variation of the taller parent might have been due to failure of the main head in many plants to emerge from the boot. It may also have been due to a positive relationship between the variance and the magnitude of the mean.

A more recent contribution to the understanding of patterns of variability in inbreeding species was made by Williams (1960) who studied variability for five characters in eight inbreds and six tomato hybrids. All plants were grown under glass where environmental variability was expected to be high compared with field conditions. Standard deviations of individual plot means were used as a measure of the relative stability of the different genotypes in the face of small random fluctuations during development, that is, the latitude allowed by a genotype to each individual in develop-

ment. For most characters the variability for F_1 hybrids fluctuated around the mid-parental value, but for flowering date low variability was transmitted as a dominant factor. Williams concluded there was no intrinsic difference between inbreds and F_1 hybrids in ability to buffer against, or eliminate, the variability induced by the environment. In this study, it was also reported that in many instances the differences in variability could be accounted for, to a large extent, by the magnitude of the means. This contrasts with the findings of Griffing and Langridge (1963) who measured the variability of fresh weight in the obligate self-fertilizing species, Arabidopsis thaliana. Hybrids were less variable over a range of constant temperatures than the parents, and they concluded that this species performs no differently than an outbreeding species.

The hypothesis put forward by Lerner (1954) was supported, however, in two recent studies with Gossypium hirsutum, a normally self-pollinated species (Kohel and White, 1963; Kohel, 1969). In these studies the results indicated that the homozygous parents exhibited greater stability than the F_1 hybrids.

In hybrids involving more than two inbreds there is the opportunity for variability arising from both genetic and environmental causes. Thus in three-way crosses the level of variability would be expected to exceed that in single-cross hybrids. Stephens and Lahr (1959), from evaluations of

three-way and single-cross grain sorghum hybrids in Texas, concluded that three-way hybrids were not necessarily more variable than single-crosses for characters such as date of bloom and plant height. However, Rosenow (1968) in reporting on the merits of using sterile single-crosses for hybrid seed production, drew attention to the fact that care should be exercised in selecting lines for the sterile single-cross so that the three-way hybrid would not be excessively variable.

The reasoning of Pinnell (1943) in relation to studies with maize may be applicable to three-way crosses and a quote seems appropriate here.

> A late inbred is thought of as carrying genes for lateness, while an early inbred has genes for earliness. A cross between such lines results in a uniform single-cross intermediate in maturity. On this basis a double-cross of the type (ExE) x (LxL) is expected to be relatively uniform and intermediate in maturity. However, in a double-cross of the (ExL) x (ExL) type, opportunity for segregation of genes for maturity would appear to be present and such a double-cross is expected to be more variable than the first (Pinnell, 1943).

Eckhart and Bryan (1940) conducted experiments with maize designed to determine whether the double-crosses produced by these two methods differed with respect to performance or variability. Three-year means showed no significant difference in yield between methods of combining the lines. In individual analyses of the data from each season the variance ascribed to method of combining was significant in one season and not in the other two. In the year when significance was indicated there was a mean difference of six bushels/acre in favor of the (ExE) x (LxL) hybrid. Plant-to-plant variability

within the two types of hybrids was studied with respect to silking date, plant height, ear height, ear weight, ear diameter, and ear length in each of two years. The variability of the (ExE) x (LxL) types was significantly lower than that of the (ExL) x (ExL) types for all characters studied. This indicates that uniformity in the double-cross may be attained by combining phenotypically similar lines in the same single-cross.

Pinnell (1943) investigated the possibility of predicting the uniformity of a double-cross in maize from a study of characters of the inbred parents. Four inbreds were selected on the basis that they were of diverse origin and differed widely in several quantitative characters. Two of the inbreds, A25 and A71, were much taller and later than the others, A111 and A158. The two types of double-crosses, (ExE) x (LxL) and (ExL) x (ExL) were produced and compared for performance and variability.

The three double-crosses did not differ by a significant amount for any character, but when plant-to-plant variability in each double-cross was analyzed, significant differences were observed. However, the differences observed did not conform with expectations. The most uniform double-cross was one of the (ExL) x (ExL) types. The explanation offered was that unrelated inbreds that look alike for a particular character very probably differ for some of the genes governing the expression of that character, so that even in the (ExE) x

(LxL) type double-cross there is opportunity for segregation. This contention might also account for the results of Eckhart and Bryan (1940), since many of the lines within each of their phenotypic classes had a common origin.

Pinnell concluded that it was impossible to predict the relative variability of double-crosses on the basis of the character means of either the inbreds or single-crosses.

Effects of Cytoplasm

Jones (1956) stated that the normal interrelationship produced by the evolution of genes and cytoplasm together provides for normal growth, development, and the transmission of characteristics to successive generations. When this relationship is altered as a result of hybridization between different types, a failure of some developmental processes may result. In plants this disturbance most often is expressed as chlorophyll degeneration or pollen abortion. The possibility that cytoplasmic differences may have effects on agronomic characters has received its greatest attention from corn breeders.

Jones (1950) compared fertile and sterile maize inbreds and hybrids having the same genotype but differing in cytoplasmic constitution. He observed that plant height, flowering time and yield were not influenced by cytoplasmic differences. From these results, and the general similarity of reciprocal crosses in maize, he concluded that varietal differences were

brought about by chromogenic differences and that the cytoplasm was basically the same.

Some workers (Rogers and Edwardson, 1952; Duvick, 1958; Chinwuba, Grogan and Zuber, 1961; Grogan et al., 1965) have reported that maize genotypes in male-sterility inducing cytoplasm will outyield the same genotypes in normal, or fertile, cytoplasm. This has been particularly apparent when the plants were subjected to stress conditions. Generally it was reasoned that the superiority of genotypes in sterile cytoplasm was the result of decreased competition for available nutrients between the tassel and ear primordia.

Duvick (1965) reported that sterile cytoplasm effects the plant before meiosis, and that it does so independently of its effect on pollen fertility. In maize lines with sterile cytoplasm and dominant restorer genes, where pollen sterility is not a factor, a yield reduction due to sterile cytoplasm was revealed. Duvick emphasized that the small magnitude of the yield reduction makes it imperative to have high numbers of replications for detecting the small differences and establishing statistical significance.

Cytoplasm effects were compared by Fleming, Kozelnicky and Browne (1960) by testing a double-cross maize hybrid made in the four possible combinations to test the effects of each inbred's cytoplasm. Significant cytoplasmic effects were obtained for plant height, flowering date, and yield. They noted that genotype x cytoplasm and cytoplasm x environment

interactions often exist. The results indicated that differences in the performance of inbreds per se do not necessarily indicate differences in their cytoplasmic effects in hybrid combinations. However, differences that did exist were in the direction expected on the basis of inbred performance. These workers concluded that in constituting a commercial double-cross an effort should be made to bring together the cytoplasm and genotype combination that gives the most efficient production in the final cross.

Little work has been reported that evaluates the effects of fertile and sterile cytoplasms on agronomic characters in sorghums. Ross (1965) found that in sorghum populations with different proportions of fertile and sterile plants, grain yields usually declined as the proportion of male-sterile plants increased. Kern (1969) presented the results of a two-year study on the effects of fertile and sterile cytoplasm on agronomic performance of grain sorghum. He found that three hybrids having sterile cytoplasm did not differ significantly from their counterparts with fertile cytoplasm for grain yield or the primary components of yield. However, in both years the fertile cytoplasm hybrids produced slightly more seeds/head and fewer heads/plant than those with sterile cytoplasm. The fertile cytoplasm hybrids bloomed slightly later and were shorter, but the differences were significant in only one year. It should be noted that in this study all hybrids were fertile, thereby allowing study of cytoplasmic

effects independent of the effects of pollen fertility. The effects of sterile and fertile cytoplasms on inbred line performance also were studied by Kern. The sterile lines produced significantly less grain, higher 100-seed weights, and fewer seeds/head than the maintainer (B) lines, and in both years the steriles bloomed significantly later than the B-lines. In this comparison, however, some lines were male sterile and some were male fertile so that the effects may be due in part to pollen fertility per se.

Quinby (1970) also studied the effects of sterile cytoplasm in sorghum hybrids. Two hybrids with sterile cytoplasm were compared with versions of the same hybrids in fertile cytoplasm over a six-year period in Texas. All hybrids were male fertile, and the two versions of each hybrid were alike genetically. Sterile cytoplasm caused a half-day delay in flowering and a 3 cm increase in plant height. These differences were statistically significant. The number of tillers/plant was not influenced by differences in cytoplasm. The two cytoplasms seemed to have no significantly different effects on grain yield. Yields of fertile and sterile cytoplasm versions of either hybrid did not differ by more than 4 q/ha in any year, and the overall mean yields of fertile and sterile cytoplasm hybrids were 49.2 and 49.3 q/ha, respectively.

MATERIALS AND METHODS

Conduct of the Experiment

The male-sterile (A) lines, maintainer (B) lines, and the fertility restoring (R) lines used in producing the grain sorghum hybrids evaluated in this study are listed below:

A-lines	B-lines	R-lines
Combine Kafir 60	Combine Kafir 60	Texas 7078
Martin	Martin	Redbine 60
Wheatland	Wheatland	Plainsman
Redlan	Redlan	Caprock

In 1966 each A-line was crossed with each B-line other than its counterpart to give 12 male-sterile single-crosses. Sixteen fertile single-crosses were produced in 1968 by crossing each A-line with each of the R-lines. Also in 1968, the 12 male-sterile single-crosses were crossed with each of the R-lines to produce 48 three-way cross hybrids. The 12 parental lines, 12 male-sterile single-crosses, 16 fertile single-crosses, and 48 three-way crosses provided a total of 88 entries for my experiments. Two experiments were planted at the Iowa State University Agronomy Farm, Ames, on May 23, 1969. Both experiments were repeated in 1970 with plantings made on May 20.

In one experiment, hereafter referred to as the yield test, the entries were planted in single-row plots, 20 feet long and 40 inches apart, using a randomized complete block

design with two replicates. Plots were thinned after emergence, leaving a three-inch interval between plants in a row. During thinning care was taken not to favor either the smaller or the more vigorous plants so that final stands would be truly representative for each entry. The central 16 feet of each plot was staked for harvesting, with only fully competitive plants included in the designated area. Heads were harvested and bagged separately for each plot and dried artificially at 71°C to a grain moisture content of approximately 10%. Yields of the threshed grain were recorded in grams per plot, without further adjustment for slight grain moisture differences.

In the second experiment, hereafter referred to as the spaced test, the rows were 12 feet long and plants were thinned to give a within-row spacing of six inches. Again, care was taken to avoid any element of selection during thinning. Before the heads were exserted from the flag leaf ten competitive plants were designated in each plot for use in the collection of individual plant data. As before, all plants were treated equally, only those plants adjacent to gaps along the row or plants at the ends of rows were denied the possibility of inclusion in the sample. In a few instances grossly abnormal plants that would obviously not exsert a head were omitted from the sample.

Measurements taken on an individual plant basis and the methods of measurement were as follows:

Days to midbloom: The number of days from planting until the extrusion of anthers, or stigmas in the case of male-sterile entries, had progressed midway down the main-stalk head. This measurement is considered a reasonable index of relative length of the growing period among grain sorghum lines and presents fewer problems of measurement than does days to seed maturity.

Plant height: Height, in centimeters, from the crown to the tip of the main-stalk head, recorded at maturity.

Number of heads/plant: The number of seed-bearing heads produced by each plant, recorded at harvest time.

Grain yield: The weight, in grams, of seed produced by each plant. Before threshing the heads were dried artificially at 71°C. Grain moisture contents of approximately 10% were attained for all entries and further adjustment for slight differences in moisture content were not made.

Weight of 100-seeds: The weight, to the nearest centigram, of a sample of 100 seeds taken randomly from the threshed grain of each plant.

Number of seeds/head: The average number of seeds per head for each plant, determined in the following manner:

$$\text{seeds/head} = \frac{\text{grain yield/plant (g) x 100}}{\text{wt. of 100-seeds (g) x no. of heads/plant}}$$

From the individual plant measurements recorded for each plot, a plot mean and a within-plot standard deviation was calculated for each character. The within-plot standard deviation (SD) was calculated in the following way:

$$SD = \sqrt{\frac{\Sigma x^2 - \frac{(\Sigma x)^2}{10}}{9}}$$

where x represents the individual plant measurements in a particular plot.

Estimation of Combining Ability Effects

The general combining ability effect of each male parent in the fertile single-crosses was estimated as the difference between the mean of all fertile single-crosses involving that particular male parent and the mean of all fertile single-crosses. The general combining ability effect of each female parent of the fertile single-crosses was estimated in a similar manner. The specific combining ability effect for each fertile single-cross was estimated as the difference between the mean for that particular hybrid and the sum of the general effects of the parents involved plus the mean of all fertile single-crosses. The estimates for grain yield were made from the data obtained from the yield test, and those for the components of yield were made from data obtained from the spaced test.

Combining ability effects in sterile single-crosses *per se* and in sterile single-crosses as components of the three-way crosses were calculated according to the procedure outlined by Griffing (1956) for diallel crossing systems in which F_1's and reciprocals are included but not the parents. The general effects were computed according to the following formula:

$$\hat{G}_i = \frac{1}{2p(p-2)} \left[p(x_{i.} + x_{.i}) - 2x_{..} \right]$$

where G_i is the general combining ability effect of the i^{th} parent, p is the number of parents in the diallel, $x_{i.}$ is the total for hybrids having the i^{th} line as a female parent, $x_{.i}$ is the total for hybrids having the i^{th} line as a male parent, and $x_{..}$ is the grand total for all hybrids in the diallel.

Specific combining ability effects in these hybrids were computed as follows:

$$\hat{S}_{ij} = \tfrac{1}{2}(x_{ij} + x_{ji}) - \frac{1}{2p(p-2)} \left[X_{i.} + X_{.i} + X_{j.} + X_{.j} \right] + \frac{1}{(p-1)(p-2)} X_{..}$$

where S_{ij} is the specific combining ability effect associated with the hybrid involving the i^{th} and j^{th} parents, $i \neq j$, x_{ij} is the mean for the hybrid involving the i^{th} line as a seed parent and the j^{th} line as a pollen parent, x_{ji} is the reciprocal of x_{ij}, $X_{i.}$ is the total for hybrids having the

i^{th} line as a female parent, $X_{.i}$ is the total for hybrids having the i^{th} line as a male parent, $X_{j.}$ and $X_{.j}$ have similar interpretations for the j^{th} parent, $X_{..}$ is the total for all entries in the diallel and p is the number of parental lines used in the diallel.

The general combining ability effects of R-lines and sterile single-crosses in the three-way crosses, and the specific combining ability effects of individual combinations of R-lines and sterile single-crosses, were estimated from the performance of three-way hybrids in a manner analogous to that used for parents and hybrids in the fertile single-crosses.

Estimation of Reciprocal Effects

Reciprocal effects in sterile single-crosses per se and in sterile single-crosses within three-way crosses also were calculated in accordance with the methods described by Griffing (1956). These effects were calculated as:

$$\hat{R}_{ij} = \tfrac{1}{2}(x_{ij} - x_{ji})$$

where R_{ij} is the reciprocal effect associated with crosses involving the i^{th} and j^{th} parents, and x_{ij} and x_{ji} are the means of a cross and its reciprocal.

Prediction of Grain Yield of Three-Way Crosses

Two methods for predicting the yield of three-way crosses were evaluated. One method was analogous to Method B described by Jenkins (1934) for the prediction of double-cross

performance from single-cross data. This method utilizes the performance of the four nonparental single-crosses to predict double-cross performance. In the prediction of three-way cross performance the two nonparental single-crosses were used as follows:

$$(A\ B)\ R = \tfrac{1}{2}\left[(A\ R) + (B\ R)\right]$$

where (A B) R is the three-way cross having R as a male parent and the sterile single-cross (A B) as a female parent. (AR) is the fertile single-cross involving parents A and R, and (B R) is the fertile single-cross involving parents B and R.

The second method of prediction was based on the performance of parental lines per se, and the predicted three-way cross performance was calculated as follows:

$$(A\ B)\ R = \frac{\frac{1}{2}(A' + B') + R'}{2}$$

where (A B) R is the three-way cross involving the sterile single-cross (A B) as a seed parent and line R as a pollen parent. R' is the performance of line R, and A' and B' are the performances of the A and B genotypes in normal cytoplasm. It was believed that the yield potential of sterile lines could be affected by the completeness of cross-pollination thereby allowing the possibility of bias if the performance of sterile lines were included in the prediction equation.

Statistical Development

The lines used as parents in my experiments were considered a fixed set selected from those lines that sorghum breeders might use in the development of superior hybrids for Iowa. In terms of soil conditions and other edaphic factors the replicates were considered a random sample of the conditions under which these populations might be grown in Iowa. The statistical model describing the performance of the i^{th} entry, in the j^{th} replicate in any one year was:

$$Y_{ij} = u + G_i + B_j + E_{ij}$$

where u is the mean of all entries, G_i is the discrepancy between the performance of the i^{th} entry in the j^{th} replicate and the mean of all entries which can be unambiguously attributed to the particular genotype or genotypes of that entry. B_j is the deviation from u attributable to the effect of the j^{th} replicate and E_{ij} is the experimental error associated with the measurements on that particular entry in that particular replicate.

The nature of this mixed model dictated the analysis of individual experiments, and also the tests of significance that were made. The form for the analysis of variance for each character in each experiment is shown in Table 1.

F ratios used to test for significant differences among entries were calculated as Entries M.S./Error M.S. The error mean square also was used to calculate F ratios in the tests

Table 1. Form for the analysis of variance of individual year data

Source of variation	Degrees of freedom	E.M.S.
Replications (B)	r-1 = 1	$\sigma^2_e + n\sigma^2_B$
Entries (G)	n-1 = 87	$\sigma^2_e + r\sum g_i^2/n-1$
Error (e)	(r-1)(n-1) = 87	σ^2_e
Total	(rn-1) = 175	

of significance for each of the orthogonal single-degree-of-freedom comparisons separated in the partitioning of the entries sums of squares. The form for the analysis of variance, showing the subdivision of the entries source of variation is given in Table 2.

For the analysis described in Table 1 the standard techniques for randomized complete blocks as outlined by Snedecor and Cochran (1967) were used. In calculating sums of squares for the partitioning of the entries source of variation the data for each group of entries (parents, sterile single-crosses, fertile single-crosses, and three-way crosses) were analyzed as separate experiments. Likewise, the among A-lines sums of squares were calculated by analyzing the data for A-lines using the standard techniques for randomized complete block designs. Similar analyses were made from the data for B-lines and R-lines.

Table 2. Form for the analysis of variance of individual year data, showing subdivision of entries sum of squares

Source of variation	Degrees of freedom
Replicates	1
Entries	87
Fertile singles vs three-ways	1
Hybrids vs parents	1
Sterile singles vs (fertile singles + three-ways)	1
Among parents	11
Among A-lines	3
Among B-lines	3
Among R-lines	3
A vs B-lines	1
(A + B-lines) vs R-lines	1
Among sterile single-crosses	11
Reciprocals	6
g.c.a.	3
s.c.a.	2
Among fertile single-crosses	15
g.c.a. (males)	3
g.c.a. (females	3
s.c.a.	9
Among three-way crosses	47
R-lines	3
Sterile single-crosses	11
Reciprocals	6
g.c.a.	3
s.c.a.	2
Sterile singles x R-lines	33
Reciprocals x R-lines	18
g.c.a. x R-lines	9
s.c.a. x R-lines	6
Error (reps x entries)	87
Total	175

The sterile single-crosses comprised a complete diallel set of crosses in which reciprocals but not selfs were included. Accordingly, the sterile single-cross data were analyzed using the procedures outlined by Griffing (1956) for Experimental Method 3 (Model 2).

The fertile single-crosses fit a two-way classification model with interaction, and were analyzed in accordance with the procedures described by Comstock and Robinson (1952) for their Design 2 experiment. Three-way crosses were analyzed in similar fashion. A portion of the variation among three-way crosses was attributable to variation among their sterile single-cross components. The sums of squares for this subcomponent were partitioned further by treating the sterile single-crosses within the three-way hybrids as a diallel to estimate the variation attributable to reciprocal, g.c.a., and s.c.a. effects as was done with the sterile single-crosses per se.

In the analysis of data from experiments combined over years a mixed model was assumed, that is, the two years were considered a random sample of seasons in which these sorghums might be grown, but the lines tested were thought of as a fixed sample from those lines that sorghum breeders might use in the development of superior hybrids. The form for the analysis of variance for each character in the combined experiments is shown in Table 3. For each character the F ratio for testing the entries x years source of variation was calculated using

Table 3. Form for the analysis of variance of data from combined experiments

Source of variation	Degrees of freedom	E.M.S.
Years (Y)	y-1 = 1	$\sigma^2_e + r n \sigma^2_Y + n \sigma^2_B$
Replicates/years (B)	y(r-1) = 2	$\sigma^2_e + n \sigma^2_B$
Entries (G)	n-1 = 87	$\sigma^2_e + r \sigma^2_{GY} + r \Sigma g_i^2/n-1$
Entries x years (GY)	(n-1)(y-1) = 87	$\sigma^2_e + r \sigma^2_{GY}$
Pooled error (e)	y(r-1)(n-1) = 174	σ^2_e
Total		

the mean square for the pooled error as the denominator. It was only in the analyses of data for variability in grain yield, heads/plant, and seeds/head that the entries x years mean square was not significant.

It has been pointed out by Cochran and Cox (1957) that the assumption that interaction terms have the same variance is necessary if the F test of entries against entries x years interaction mean square is to be meaningful. To determine the validity of this assumption the entries sum of squares for each character in which the entries x years mean square was significant was divided into a set of orthogonal components, namely, among A-lines, among B-lines, among R-lines, among sterile single-crosses, among fertile single-crosses, and among three-way crosses, along with single-degree-of-freedom comparisons of A vs B-lines, A and B vs R-lines, parents vs hybrids, fertile single-crosses vs three-way crosses, and sterile single-crosses vs fertile singles and three-way crosses. The entries x years interaction sums of squares were partitioned in the same manner so as to isolate the interaction of each component with years. Homogeneity of the variances for these interaction terms was evaluated by Bartletts' test, as described by Snedecor and Cochran (1967).

The results of these tests indicated that the assumption of homogeneity of variances for the interaction terms was valid for all characters for which a significant entries x years interaction had been noted, with two exceptions.

The chi-square values computed for seeds/head and 100-seed weight indicated that the interaction mean squares were heterogeneous for these traits. In the testing of differences between entries in the combined analyses, therefore, each component of the entries sum of squares was tested against its own interaction with years for the characters seeds/head and 100-seed weight, but each component was tested against the total entries x years interaction mean square in the case of the remaining characters for which entries x years had been significant, as suggested by Cochran and Cox (1957). An unavoidable drawback to this procedure is that the degrees of freedom in the denominator of F are reduced for seeds/head and 100-seed weight.

The mean square for years was tested against the replicates within years mean square for each character. This is in accord with the reasoning of LeClerg, Leonard, and Clark (1962) who regarded the analysis of data combined over years as analogous to that of a split-plot experiment in which years were thought of as main plots. The mean square for replicates within years then would be analogous to Error (a) in a simple split-plot experiment.

The combined analyses were calculated for 100-seed weight, heads/plant, days to midbloom, and plant height even though the F ratio of S_1^2/S_2^2, where S_1^2 and S_2^2 were the larger and smaller error mean squares from individual year analyses respectively, indicated that the error variances for these traits

were significantly different between years (P = .05), when compared with tabulated 5% probability levels of F (two-tailed). The use of the combined analyses is justified by the fact that the F test of entries mean squares against entries x years interaction mean squares is little affected by inequality in the error variances when the interactions are large, Cochran and Cox (1957). Similar F tests indicated that error mean squares for grain yield and seeds/head were statistically equivalent over years.

A combined analysis of within-plot variability was calculated for each character, although F tests had shown error terms to be heterogeneous over years, and entries x years to be insignificant for variability in seeds/head and heads/plant. The combined analyses for variability in these characters were calculated since within-plot variability for seeds/head and heads/plant was considered to be of minor importance and it was deemed desirable to treat all of the variability data in a consistent manner.

EXPERIMENTAL RESULTS

Rainfall and temperature conditions at Ames, Iowa, during 1969 and 1970 were suitable for good growth and development of sorghum. The mean yield, in bushels/acre, for all entries was 101 in 1969 and 107 in 1970. Although plant growth did not seem stressed in either year, the lower yield in 1969 may have resulted, at least in part, from lodging that followed a severe windstorm on September 6 which seemed to affect all entries equally, and the failure of some male-sterile types to attain full seed-set.

The experimental results will be presented in the following order: (1) grain yield and its primary components; (2) predictions of grain yields of three-way crosses; (3) plant height and days to midbloom; (4) within-plot variability.

Grain Yield and Yield Components

In the presentation of yield and yield component data grain yield will refer to grain yield obtained in the yield test and the components will refer to yield components measured in the spaced test. Table 4 shows the analyses of variance for grain yield, 100-seed weight, seeds/head, and heads/plant. F tests made from the combined analyses indicated there were significant differences between years for grain yield and for each of its primary components, and between entries for grain yield and heads/plant. A significant entries x years interaction

Table 4. Analyses of variance for grain yield and yield components for combined 1969 and 1970 experiments

Source of variation	Degrees of freedom	Mean squares			
		Grain yield	100-seed weight	Seeds/ head	Heads/ plant
Years	1	3430172**	4.330**	2398352**	22.756**
Replicates/years	2	24656	0.015	99179	0.225
Entries	87	259838**	0.405	356920	0.134**
Entries x years	87	72932**	0.079**	103516*	0.105*
Pooled error	174	47766	0.049	69203	0.076

*, **In this table and all tables hereafter, one and two asterisks indicate significant differences at the five and one percent probability levels, respectively.

was indicated for each character. The variation attributable to replicates within years was not significant for any character.

The mean squares derived by partitioning the entries sums of squares, and the levels of significance obtained when tested against the appropriate mean square, are given in Table 5. Significant differences in grain yield were indicated among R-lines, among fertile single-crosses and among three-way crosses. The variation among A-lines was highly significant ($P = .01$) for heads/plant. A similar result, at a lower probability ($P = .05$), was found for the R-lines. Significant differences among the R-lines ($P = .05$), among sterile single-crosses ($P = .01$), and among fertile single-crosses ($P = .05$) were found for seeds/head. Variation among fertile single-crosses and among three-way crosses for 100-seed weight was significant at the .05 and .01 probability levels, respectively.

In addition to examining the variation among parental and hybrid types, differences between these types also were analyzed. Among the parents, the performances of A-lines and their B-line counterparts were contrasted, as were the A and B-lines with the R-lines. A-lines also were compared with sterile single-cross hybrids. Among the different hybrid types, fertile single-crosses were compared with three-way crosses, and sterile single-crosses with fertile singles plus three-way hybrids. The latter comparison contrasts the performance of fertile and sterile hybrids. In addition, the

Table 5. Line, hybrid, line x year, and hybrid x year mean squares from analyses of variance for grain yield and yield components for combined 1969 and 1970 experiments

Source of variation	Degrees of freedom	Mean squares			
		Grain yield	100-seed weight	Seeds/ head	Heads/ plant
A-lines	3	83978	0.183	480715	0.431**
A-lines x years	3	214607**	0.031	359518**	0.132
B-lines	3	30002	0.141	161779	0.039
B-lines x years	3	43411	0.030	130625	0.087
R-lines	3	221541*	0.173	507163*	0.367*
R-lines x years	3	101574	0.027	43595	0.032
Sterile single-crosses	11	119062	0.071	128808**	0.054
Sterile singles x years	11	49121	0.044	26916	0.087
Fertile single-crosses	15	138510*	0.099*	226874*	0.110
Fertile singles x years	15	95586*	0.026	69543	0.098
Three-way crosses	47	127394*	0.093**	108955	0.118
Three-ways x years	47	58779	0.025	89515	0.109
Entries x years	87	72932**	0.079**	103516*	0.105*
Pooled error	174	47766	0.049	69203	0.076

performance of hybrids as a group was contrasted with that of parents as a group.

Single crosses vs three-way crosses

Mean squares for selected comparisons between the hybrid groups are given in Table 6. A main objective of this study was to compare the productivity of three-way hybrids and fertile single-crosses. Table 6 indicates that these hybrid types did not differ significantly in grain yield, or for any of the primary components of yield, when two-year means were analyzed. These results were found also in each of the individual years (Appendix Tables 66 and 67). The lack of significance for the fertile single-cross vs three-way hybrid comparison indicated that the means of single-crosses and three-way hybrids as groups were equivalent.

Examination of the group means alone may not fully characterize the relative merits of the two hybrid types, however, since individual hybrids within one group may outperform the best hybrid in the other group even though group means are equivalent. Accordingly, the range of values within each group is of interest. Means of fertile single-crosses and three-way hybrids as groups, and the range observed among the means within each group, for grain yield and its components are presented in Table 7. Generally, the ranges for individual hybrid means were similar within both groups. Based on an LSD .05 of 380 g for grain yield (computed from the combined

Table 6. Mean squares for hybrids vs parents and between hybrid-group comparisons for grain yield and components of yield from analyses of combined 1969 and 1970 experiments

Source of variation	Degrees of freedom	Mean squares			
		Grain yield	100-seed weight	Seeds/ head	Heads/ plant
Hybrids vs parents	1	10813645**	1.059*	4607030	0.312
Hybrids vs parents x years	1	306027*	0.002	465764**	0.310*
Fertile singles vs three-ways	1	108561	0.000	974	0.055
Fertile singles vs three-ways x years	1	8	0.000	52984	0.203
Sterile singles vs (fertile singles + three-ways)	1	738480**	15.876	8101966	0.766**
Sterile singles vs (fertile singles + three-ways) x years	1	821	1.619**	1225822**	0.038
Entries x years	87	72932**	0.079**	103516*	0.105*
Pooled error	174	47766	0.049	69203	0.076

Table 7. Hybrid-group means and range of individual hybrid means within groups for grain yield and its components from individual and combined 1969 and 1970 experiments

Year and hybrid type	Parameter	Character			
		Grain yield (g/plot)	100-seed weight (g)	Seeds/ head	Heads/ plant
1969					
Fertile singles	Mean	3432	2.36	2366	2.13
	Range	2850 - 3843	2.06 - 2.67	1998 - 2972	1.70 - 2.55
Three-ways	Mean	3384	2.37	2328	2.16
	Range	2970 - 3912	1.99 - 2.83	1864 - 2749	1.55 - 2.80
1970					
Fertile singles	Mean	3654	2.62	2454	1.70
	Range	3250 - 3845	2.32 - 2.83	2054 - 2848	1.40 - 2.30
Three-ways	Mean	3606	2.61	2483	1.60
	Range	3203 - 4176	2.24 - 2.87	1876 - 2969	1.15 - 2.00
1969 and 1970					
Fertile singles	Mean	3543	2.49	2410	1.91
	Range	3159 - 3803	2.20 - 2.70	2064 - 2910	1.67 - 2.32
Three-ways	Mean	3495	2.49	2405	1.88
	Range	3106 - 3949	1.98 - 2.85	2075 - 2720	1.47 - 2.17

analysis) the two-year means for the highest yielding hybrids from each group were statistically equivalent, as were those of the lowest yielding hybrids. The data for each of the yield components (Tables 6 and 7) indicated there were no significant differences in yield structure between the single and three-way crosses.

Two-year means for grain yield and its components are listed individually for each fertile single-cross and three-way cross in Tables 8 and 9. Mean squares from the combined analysis for grain yield and its components in fertile single-crosses and three-way crosses are given in Tables 10 and 11, respectively.

Table 10 shows that general combining ability effects of both the male and female parents contributed significantly to the variation in grain yield among fertile single-crosses, but specific combining ability effects did not. The mean squares in Table 10 show further that the interaction of fertile single-crosses with years was significant ($P = .05$) for grain yield. Partitioning this source of variation further showed that the interaction of fertile single-crosses with years included significant interactions of g.c.a. (females) and s.c.a. with years. The nature of these interactions may be seen from the general and specific effects presented for fertile single-crosses in Tables 12 and 13. In 1969 highly significant differences ($P = .01$) between the general effects of both male and female parents were observed (Appendix Table

Table 8. Means for grain yield and its primary components of fertile single-crosses from combined 1969 and 1970 experiments

Fertile single-cross	Character			
	Grain yield (g/plot)	100-seed weight (g)	Seeds/ head	Heads/ plant
A Kafir 60 x Tx 7078	3689	2.47	2255	2.15
x Redbine 60	3472	2.70	2367	1.77
x Plainsman	3397	2.35	2229	1.92
x Caprock	3728	2.70	2380	1.95
A Martin x Tx 7078	3354	2.46	2385	1.83
x Redbine 60	3305	2.61	2064	1.90
x Plainsman	3159	2.25	2414	1.85
x Caprock	3653	2.50	2793	1.75
A Wheatland x Tx 7078	3561	2.40	2119	2.32
x Redbine 60	3604	2.64	2567	1.67
x Plainsman	3347	2.20	2227	2.02
x Caprock	3607	2.59	2316	2.02
A Redlan x Tx 7078	3623	2.34	2748	2.00
x Redbine 60	3804	2.67	2451	1.80
x Plainsman	3582	2.46	2327	1.80
x Caprock	3795	2.44	2910	1.80
LSD .05	380	0.25	281	ns

Table 9. Means for grain yield and its primary components of three-way crosses from combined 1969 and 1970 experiments

Three-way hybrid	Character			
	Grain yield (g/plot)	100-seed weight (g)	Seeds/ head	Heads/ plant
(A K x B M) x Tx 7078	3474	2.50	2365	2.15
(A M x B K) x Tx 7078	3421	2.41	2426	2.00
(A K x B M) x Redbine 60	3390	2.63	2247	1.92
(A M x B K) x Redbine 60	3618	2.52	2151	2.17
(A K x B M) x Plainsman	3242	2.25	2698	1.67
(A M x B K) x Plainsman	3208	2.13	2533	1.97
(A K x B M) x Caprock	3717	2.52	2486	1.80
(A M x B K) x Caprock	3574	2.39	2355	1.90
(A K x B W) x Tx 7078	3727	2.47	2327	2.02
(A W x B K) x Tx 7078	3352	2.60	2205	2.10
(A K x B W) x Redbine 60	3554	2.55	2518	1.77
(A W x B K) x Redbine 60	3388	2.85	2075	2.00
(A K x B W) x Plainsman	3274	2.29	2424	1.92
(A W x B K) x Plainsman	3278	2.32	2380	1.77
(A K x B W) x Caprock	3550	2.50	2272	2.10
(A W x B K) x Caprock	3758	2.66	2307	1.85
(A K x B R) x Tx 7078	3950	2.38	2477	2.00
(A R x B K) x Tx 7078	3677	2.36	2567	1.85
(A K x B R) x Redbine 60	3672	2.75	2353	1.65
(A R x B K) x Redbine 60	3538	2.63	2494	1.65
(A K x B R) x Plainsman	3454	2.48	2358	2.02
(A R x B K) x Plainsman	3583	2.50	2169	2.00
(A K x B R) x Caprock	3718	2.67	2720	1.47
(A R x B K) x Caprock	3795	2.69	2693	1.63
(A M x B W) x Tx 7078	3288	2.73	2324	1.67
(A W x B M) x Tx 7078	3447	2.50	2120	2.07
(A M x B W) x Redbine 60	3493	2.62	2296	1.95
(A W x B M) x Redbine 60	3429	2.67	2096	2.07
(A M x B W) x Plainsman	3107	2.31	2418	1.70
(A W x B M) x Plainsman	3243	2.38	2476	1.80

A K = A Kafir 60 — B K = B Kafir 60
A M = A Martin — B M = B Martin
A W = A Wheatland — B W = B Wheatland
A R = A Redlan — B R = B Redlan

Table 9. (Continued)

Three-way hybrid	Character			
	Grain yield (g/plot)	100-seed weight (g)	Seeds/ head	Heads/ plant
(A M x B W) x Caprock	3556	2.49	2401	2.10
(A W x B M) x Caprock	3552	2.44	2427	2.02
(A M x B R) x Tx 7078	3663	2.49	2533	1.85
(A R x B M) x Tx 7078	3679	2.47	2323	2.05
(A M x B R) x Redbine 60	3313	2.43	2305	1.97
(A R x B M) x Redbine 60	3475	2.51	2490	1.63
(A M x B R) x Plainsman	3395	2.24	2563	1.75
(A R x B M) x Plainsman	3391	2.31	2372	1.95
(A M x B R) x Caprock	3522	2.67	2713	1.60
(A R x B M) x Caprock	3659	2.46	2635	1.85
(A W x B R) x Tx 7078	3568	2.36	2397	1.82
(A R x B W) x Tx 7078	3505	2.52	2431	2.02
(A W x B R) x Redbine 60	3425	2.67	2671	1.52
(A R x B W) x Redbine 60	3407	2.44	2367	1.82
(A W x B R) x Plainsman	3204	2.24	2175	2.00
(A R x B W) x Plainsman	3328	2.38	2398	1.80
(A W x B R) x Caprock	3689	2.57	2621	1.80
(A R x B W) x Caprock	3526	2.57	2298	1.87
LSD .05	380	ns	ns	ns

66), but in 1970 (Appendix Table 67) general effects were not significant for either male or female parents. Among the male parents there was little difference in their relative merit for g.c.a. for grain yield between years (Tables 12 and 13), but among female parents some changes in ranking for g.c.a. were evident. The relative merits of A Wheatland and A Kafir 60 were notably different in the two years. In 1969 the general

Table 10. Analyses of variance for grain yield and yield components of fertile single-crosses from combined 1969 and 1970 experiments

Source of variation	Degrees of freedom	Mean squares			
		Grain yield	100-seed weight	Seeds/ head	Heads/ plant
Among fertile single-crosses	15	138510*	0.099*	226874*	0.110
g.c.a. (females)	3	302208**	0.037	323542*	0.117
g.c.a. (males)	3	282823*	0.368**	275722	0.230
s.c.a.	9	35951	0.031	178369	0.068
Fertile single-crosses x years	15	95586*	0.026	69543	0.098
g.c.a. (females) x years	3	172416*	0.067	107853	0.164
g.c.a. (males) x years	3	20036	0.013	47100	0.011
s.c.a. x years	9	95159*	0.017	64254	0.104
Entries x years	87	72932**	0.079**	103516*	0.105*
Pooled error	174	47766	0.049	69203	0.076

Table 11. Analyses of variance for grain yield and yield components of three-way crosses from combined 1969 and 1970 experiments

Source of variation	Degrees of freedom	Mean squares			
		Grain yield	100-seed weight	Seeds/ head	Heads/ plant
Years	1	2379856**	3.020**	1149251**	15.075**
Among three-way crosses	47	127394*	0.093**	108955	0.118
R lines	3	945537**	0.759**	213097	0.183
Sterile single-crosses	11	148983*	0.068**	118709	0.108
reciprocals	6	25960	0.053	63728	0.066
g.c.a.	3	433418**	0.056	305400*	0.244
s.c.a.	2	91400	0.131	3616	0.030
Sterile singles x R lines	33	45821	0.041	96236	0.115
reciprocals x R lines	18	51567	0.029	66519	0.089
g.c.a. x R lines	9	50207	0.077*	192788*	0.237*
s.c.a. x R lines	6	22004	0.022	4056	0.010
Three-way crosses x years	47	58779	0.025	89515	0.109
R lines x years	3	27153	0.097	188899*	0.504**
Sterile singles x years	11	41263	0.052	140375*	0.153*
reciprocals x years	6	35893	0.020	161417*	0.174*
g.c.a. x years	3	59253	0.140*	83500	0.089
s.c.a. x years	2	30388	0.016	162562	0.186

Table 11. (Continued)

Source of variation	Degrees of freedom	Mean squares			
		Grain yield	100-seed weight	Seeds/ head	Heads/ plant
(Sterile singles x R lines) x years	33	67460	0.009	63527	0.058
(reciprocals x R lines) x years	18	67752	0.014	78193	0.087
(g.c.a. x R lines) x years	9	76230	0.010	61848	0.020
(s.c.a. x R lines) x years	6	53429	0.000	22046	0.031
Entries x years	87	72932**	0.079**	103516*	0.105*
Pooled error	174	47766	0.049	69203	0.076

Table 12. General and specific combining ability effects for grain yield in fertile single-crosses, 1969

Female parent	Male parent				General effects of females
	Tx 7078	Redbine 60	Plainsman	Caprock	
			Specific effects		
Kafir 60	- 7	-144	214	- 64	108
Martin	- 42	-172	81	132	-289
Wheatland	108	145	-299	46	- 73
Redlan	- 59	171	3	-114	255
General effects of males	31	- 15	-210	193	

Table 13. General and specific combining ability effects for grain yield in fertile single-crosses, 1970

Female parent	Male parent				General effects of females
	Tx 7078	Redbine 60	Plainsman	Caprock	
			Specific effects		
Kafir 60	212	- 62	-221	71	- 50
Martin	- 13	39	-156	132	- 61
Wheatland	- 75	- 4	276	-198	48
Redlan	-122	30	105	- 2	59
General effects of males	- 3	22	-133	113	

effects for A Wheatland and A Kafir 60 were -73 and 108 g respectively (Table 12), but the corresponding values in 1970 (Table 13) were 48 and -50 g.

Although s.c.a. differences did not make a significant contribution to the yield variation among fertile single-crosses in either year (Appendix Tables 66 and 67), the interaction between s.c.a and years was significant for grain yield in the combined-year analysis (Table 10). Again, reference to Tables 12 and 13 provides insight into the nature of this interaction. The interaction was most striking in the comparisons of specific effects for the Kafir 60 x Plainsman and Wheatland x Plainsman crosses over years. Specific effects for the Kafir 60 x Plainsman hybrid were 214 g in 1969 compared with -221 g in 1970, but the specific effects for Wheatland x Plainsman went from -299 g in 1969 to 276 g in 1970.

General and specific combining ability effects determined from the mean yields of fertile single-crosses over the two years are shown in Table 14. Redlan was outstanding among the female parents, and Caprock among the male parents, in general combining ability. In contrast, low g.c.a. was indicated for the Martin (female) and Plainsman (male) parents. Specific combining ability effects were decidedly the greatest for the Martin x Caprock, Kafir 60 x Tx 7078, and Redlan x Redbine 60 hybrids.

Significant differences ($P = .05$) among fertile single-crosses were indicated in the combined analyses for grain yield,

Table 14. General and specific combining ability effects for grain yield in fertile single-crosses, from combined 1969 and 1970 experiments

Female parent	Male parent				General effects of females
	Tx 7078	Redbine 60	Plainsman	Caprock	
			Specific effects		
Kafir 60	103	-103	- 3	3	29
Martin	- 29	- 67	- 38	131	-174
Wheatland	16	70	- 12	- 77	- 12
Redlan	- 93	99	52	- 60	159
General effects of males	15	4	-171	154	

seeds/head, and 100-seed weight (Table 10). The means presented in Table 8 show that hybrids involving either Redlan or Kafir 60 female parent usually were higher yielding than those involving either Wheatland or Martin. Hybrids involving the Caprock male parent consistently gave yields equivalent to the highest yielding fertile single-cross (Redlan x Redbine 60). In addition, of the three hybrids with highest numbers of seeds/head, Redlan and Caprock each were involved twice as a parent.

Significant differences among three-way crosses were observed only for grain yield and 100-seed weight. The highest yielding three-way hybrid was (A Kafir 60 x B Redlan) x Tx 7078,

which had a mean yield of 3950 g/plot (Table 9). The lowest yielding three-way hybrid was (A Martin x B Wheatland) x Plainsman, which had a mean of 3107 g/plot. The mean yield of three-way crosses as a group was 3495 g/plot.

The significant variation among three-way crosses for grain yield and 100-seed weight (Table 11) resulted largely from differences attributable to the male parents (R-lines). Table 15 shows the general and specific combining ability effects for grain yield in the three-way hybrids. In keeping with the data for fertile single-crosses (Table 14) Caprock exhibited the greatest g.c.a. among male parents and Plainsman showed the least. Among the female parents, A Kafir 60 x B Redlan was highest in g.c.a. and A Martin x B Wheatland was lowest. Partitioning the among sterile single-cross source of variation for grain yield of the three-way crosses (Table 11) showed that the differences in g.c.a. of female single-cross parents resulted largely from differences in the g.c.a. of the parents of the sterile single-crosses.

Table 16 shows the g.c.a. effects of the parents of sterile single-crosses as measured from the performance of the three-way hybrids. The effects are shown individually for each R-line as well as for all R-lines. The data indicate that the relationships between combining ability effects for grain yield of the four parental line components of the sterile single-crosses, as measured in three-way crosses, were similar to those observed for the same lines when they were used in

Table 15. General and specific combining ability effects for grain yield in three-way crosses from combined 1969 and 1970 experiments

Female parent	Male parent				General effects of females
	Tx 7078	Redbine 60	Plainsman	Caprock	
	Specific effects				
Kafir 60 x Martin	- 50	- 46	- 28	121	- 39
Martin x Kafir 60	-102	183	- 61	- 21	- 40
Kafir 60 x Wheatland	133	48	- 66	-116	31
Wheatland x Kafir 60	-160	- 36	20	174	- 51
Kafir 60 x Redlan	184	- 6	- 58	-120	203
Redlan x Kafir 60	- 39	- 90	121	7	153
Martin x Wheatland	-141	152	- 68	55	-134
Wheatland x Martin	- 39	31	11	- 6	- 77
Martin x Redlan	122	-140	108	- 91	- 22
Redlan x Martin	60	- 56	26	- 32	56
Wheatland x Redlan	28	- 27	- 82	77	- 23
Redlan x Wheatland	- 4	- 14	73	- 55	- 54
General effects of males	68	- 20	-186	140	

Table 16. General combining ability effects of parents of sterile single-crosses, measured in three-way crosses, for grain yield, and its components, in combined 1969 and 1970 experiments

Character and R-line	Parents of sterile single-crosses			
	Kafir 60	Martin	Wheatland	Redlan
	General combining ability effects			
Grain yield				
Tx 7078	56	-101	-122	166
Redbine 60	77	- 33	- 39	- 5
Plainsman	46	- 67	-104	125
Caprock	76	- 57	- 44	25
All R-lines	64	- 65	- 78	78
100-seed weight				
Tx 7078	-0.04	0.05	0.07	-0.08
Redbine 60	0.07	-0.06	0.04	-0.05
Plainsman	0.01	-0.07	0.00	0.06
Caprock	0.03	-0.09	-0.02	0.08
All R-lines	0.02	-0.04	0.02	0.00
Seeds/head				
Tx 7078	30	- 39	-111	120
Redbine 60	- 48	-112	- 2	162
Plainsman	20	144	- 52	-112
Caprock	- 32	13	- 159	179
All R-lines	- 8	2	- 81	88
Heads/plant				
Tx 7078	0.08	-0.00	-0.03	-0.05
Redbine 60	0.03	0.17	0.02	-0.20
Plainsman	0.04	-0.08	-0.05	0.09
Caprock	-0.06	0.07	0.19	0.19
All R-lines	0.02	0.04	0.03	-0.09

fertile single-crosses (Table 14). Redlan again was highest and Wheatland and Martin were low in general combining ability. Reciprocal effects among the sterile single-cross parents of three-way crosses seemed to contribute little to the overall variation among these hybrids (Table 11).

The significant interaction between fertile single-crosses and years (Table 10) and the lack of significant interaction between three-way crosses and years for grain yield (Table 11) suggests that stability of performance may be greater in three-way crosses. These results, however, were obtained from only two environments (years), and conclusions about relative stability of the different hybrid-types are, therefore, not firmly supported. The possibility that individual single-crosses may show greater stability than the most stable three-way hybrid is not precluded by these results.

The fertile single-crosses and three-way hybrids, as groups, did not differ significantly for any of the primary components of grain yield (Table 6). Differences in g.c.a. effects of the parents, however, did contribute significantly to the variation within both types of hybrids for 100-seed weight and seeds/head (Tables 10 and 11). General combining ability effects of the parents in fertile single-crosses and in three-way crosses, are shown for the three yield components in Table 17. A close relationship between the general combining abilities of parental lines measured in fertile single-crosses and in three-way crosses is indicated by the data. For

Table 17. General combining ability effects for yield components of parental lines in fertile single-crosses and in three-way crosses from combined 1969 and 1970 experiments

Parental lines	Character and type of cross					
	100-seed weight		Seeds/head		Heads/plant	
	Fertile singles	Three-ways	Fertile singles	Three-ways	Fertile singles	Three-ways
	General combining ability effects					
Females						
Kafir 60	0.07	0.02	-102	- 8	0.04	0.02
Martin	-0.03	-0.04	4	2	-0.08	0.04
Wheatland	-0.03	0.02	-103	-81	0.10	0.03
Redlan	-0.01	0.00	199	87	-0.06	-0.09
Level of significance	ns	ns	*	*	ns	ns
Males						
Tx 7078	-0.07	-0.01	- 34	-30	0.16	0.09
Redbine 60	0.17	0.12	- 48	-66	-0.12	-0.04
Plainsman	-0.17	-0.17	-111	9	-0.01	-0.02
Caprock	0.07	0.06	190	89	-0.03	-0.05
Level of significance	**	**	ns	ns	ns	ns

those characters where the analyses had shown that the female parents in fertile single-crosses did not exhibit significant differences in g.c.a. (i.e., 100-seed weight and heads/plant) the analyses for the three-way cross data gave a similar result. This pattern also was evident among the male parent effects. When general combining abilities in single-crosses did not differ significantly, the same was true in three-way crosses. In the two instances where significant differences in g.c.a. were expressed, namely, between female parents for seeds/head and between male parents for 100-seed weight, the rankings of parents for g.c.a. were nearly the same in the single and three-way crosses. Redbine 60 exhibited the highest g.c.a. and Plainsman was the poorest combiner among the male parents for 100-seed weight in both groups of hybrids. Among the female parents, Redlan had the highest general effect for seeds/head in both types of hybrids, and Wheatland had the lowest.

Although the mean square for specific combining ability of individual combinations of R-lines and sterile single-crosses was not significant for grain yield or any of its components in the combined analyses of three-way cross data (Table 11) a factor contributing to s.c.a. was significant for each of the yield components. This factor was the variation due to interactions between the R-lines and general combining abilities of the parents of sterile single-crosses and it was significant ($P = .05$) for 100-seed weight, seeds/head and

heads/plant. The g.c.a. effects of the parents of sterile single-crosses in combination with each of the R-lines (Table 16) may serve to illustrate this interaction. The general combining abilities of Kafir 60, Martin, Wheatland and Redlan show distinct interactions with the R-lines in this set of data. One of the most pronounced interactions was for 100-seed weight, where the ranking of general effects of the four female parents in crosses with Tx 7078 was nearly the reverse of that observed in crosses with Caprock. Similarly, the rankings for general effects for seeds/head differed appreciably when calculated with the Plainsman R-line as opposed to either Tx 7078 or Caprock, and for heads/plant when determined from crosses with Plainsman in contrast to Caprock.

The combined analyses of yield component data for the three-way crosses (Table 11) indicated that reciprocal effects within the sterile single-cross parents were not significant. However, in the individual year analyses (Appendix Tables 66 and 67) reciprocal effects were significant for seeds/head and heads/plant in 1970, but not in 1969. This differential performance did not lie within the limits of experimental error as shown by the significant interaction between reciprocal effects and years (Table 11). The interaction with years was particularly noticeable for heads/plant (Table 18). In four of the six pairs of reciprocal crosses there was a change in the direction of the effect, and in two pairs there was a change in the magnitude of the effects between years. For

Table 18. Reciprocal effects for yield components in sterile single-cross parents of three-way crosses, 1969 and 1970

Sterile single-cross	Character and year					
	100-seed weight		Seeds/head		Heads/plant	
	1969	1970	1969	1970	1969	1970
	Reciprocal Effects					
A Kafir x B Martin A Martin x B Kafir	0.08	0.04	-99	182	0.10	-0.22
A Kafir x B Wheatland A Wheatland x B Kafir	-0.08	-0.08	45	98	0.05	-0.02
A Kafir x B. Redlan A Redlan x B Kafir	0.07	-0.04	-29	26	0.01	-0.01
A Martin x B Wheatland A Wheatland x B Martin	0.02	0.02	-53	134	0.01	-0.15
A Martin x B Redlan A Redlan x B Martin	-0.02	0.03	58	16	-0.02	-0.06
A Wheatland x B Redlan A Redlan x B Wheatland	-0.01	-0.01	39	54	-0.02	-0.08

seeds/head a change in direction was observed for reciprocal effects in three pairs of reciprocal crosses and a change in magnitude was indicated for the other three. The reciprocal effects for 100-seed weight (Table 18) seemed to bear out the lack of significant interaction for reciprocals x years that was shown in the combined analysis (Table 11).

A-lines vs sterile single-crosses

The performance of sterile single-crosses was compared with that of the A-lines, since the use of sterile single-crosses as seed parents in the production of three-way hybrids is analogous to the use of A-lines in the production of single-crosses. Means of the A-lines and sterile single-crosses for grain yield and its components in the 1969 and 1970 experiments, together with the two-year means are presented in Table 19. Mean squares for single-degree-of-freedom comparisons of A-lines and sterile single-crosses for the individual and combined year data and for the interaction of A-lines vs sterile singles with years are presented in Table 20. In 1969 the sterile single-crosses outyielded the A-lines, produced more seeds/head and heads/plant, and the two types were nearly alike for 100-seed weight. However, none of the differences showed statistical significance. In 1970 means of the sterile single-crosses were significantly higher ($P = .01$) for grain yield and seeds/head, but 100-seed weight was significantly greater in the A-lines. In contrast

Table 19. Means of A-lines and sterile single-crosses for grain yield and its components from 1969 and 1970 experiments, and combined over both years

Year and population type	Character			
	Grain yield (g/plot)	100-seed weight (g)	Seeds/ head	Heads/ plant
1969				
A-lines	2876	3.21	1540	1.84
Sterile singles	3265	3.19	1715	2.04
Level of significance	ns	ns	ns	ns
1970				
A-lines	2780	3.34	1570	1.64
Sterile singles	3478	3.04	2202	1.50
Level of significance	**	**	**	ns
1969 and 1970				
A-lines	2828	3.27	1555	1.74
Sterile singles	3372	3.12	1958	1.75
Level of significance	**	ns	ns	ns

to 1969, the sterile single-crosses had fewer heads/plant in 1970 than did the A-lines, but the difference was not significant. The two-year means indicated that sterile single-crosses were superior for grain yield. The A-lines had fewer and larger seeds than did the sterile single-crosses, but the differences were not significant. The mean number of heads/plant over the two years was almost identical for both groups.

Table 20. Mean squares and levels of significance for single-degree-of-freedom comparisons of A-lines and sterile single-crosses for grain yield and its components in 1969 and 1970, and both years combined

Comparison	Degrees of freedom	Mean squares			
		Grain yield	100-seed weight	Seeds/ head	Heads/ plant
1969					
A-lines vs sterile singles	1	908315	0.002	184363	0.250
1970					
A-lines vs sterile singles	1	2924271**	0.530**	2394016**	0.201
1969 and 1970					
A-lines vs sterile singles	1	3546066**	0.298	1953545	0.001
(A-lines vs sterile singles) x years	1	286520*	0.234	624834**	0.450*
Entries x years	87	72932	0.079	103516	0.105
Pooled error	174	47766	0.049	69203	0.076

Table 20 also shows that the relationship between A-line and sterile single-cross means did not remain the same over years for grain yield, seeds/head and heads/plant. For heads/plant a reversal of superiority was exhibited with the sterile singles superior in 1969 and the A-lines higher in 1970 (Table 19). The interaction for seeds/head resulted from a markedly greater divergence of the means in 1970. The mean number of seeds/head remained virtually unchanged over years in the A-lines but the mean for sterile single-crosses increased about 30% in 1970. Similarly, the increase in grain yield of the sterile single-crosses from 1969 to 1970 was about double that shown by the A-lines.

In 1969 Wheatland and Redlan were the highest yielding A-lines, but their position relative to the other A-lines was reversed in 1970 (Table 21). The shift in performance was especially pronounced for Wheatland, which seemed enough in itself to account for the significant A-line x years interaction.

A striking feature of the data was the differential performance of A and B-lines. For all characters in each year, except 100-seed weight in 1969, the differences among A-lines were significant (Appendix Tables 66 and 67). Their B-line counterparts, however, did not differ significantly for any character in either year, with one exception (seeds/head in 1970).

Two-year means for grain yield and its components in the

Table 21. Means for grain yield and its primary components of A, B and R lines, 1969 and 1970

Parental line	Character and year							
	Grain yield (g/plot)		100-seed weight (g)		Seeds/head		Heads/plant	
	1969	1970	1969	1970	1969	1970	1969	1970
A Kafir 60	2508	2897	3.22	3.29	1222	1482	2.00	1.80
A Martin	2914	3093	3.00	3.03	1551	2247	2.10	1.40
A Wheatland	3029	2404	3.53	3.55	1390	1040	2.05	2.00
A Redlan	3054	2727	3.08	3.47	2098	1511	1.30	1.35
B Kafir 60	2886	3034	2.50	2.60	2204	2194	1.90	1.70
B Martin	3021	3244	2.20	2.52	2104	2738	2.25	1.35
B Wheatland	2995	2885	2.61	2.68	1993	1944	2.05	1.65
B Redlan	3115	2899	2.86	2.76	2123	1953	1.85	1.40
R Tx 7078	2990	2906	2.33	2.71	2000	1678	2.10	1.95
R Redbine 60	2852	3523	2.19	2.75	2139	2162	2.30	1.75
R Plainsman	2783	2907	1.87	2.27	2733	2368	1.50	1.30
R Caprock	3259	3474	2.36	2.53	2584	2595	1.85	1.50

sterile single-crosses are presented in Table 22. The combined analyses (Table 5) indicated that these hybrids did not differ significantly for any of these characters, except seeds/head. The variation among sterile single-crosses was partitioned further into reciprocal, g.c.a., and s.c.a. sources of variation. The mean squares for these sources of variation and their interaction with years are shown in Table 23. Neither reciprocal nor general or specific combining ability effects caused significant variation among the sterile single-crosses. Likewise, the interactions of these effects with years were not significant for grain yield or any of its components.

Sterile vs fertile hybrids

In 1969 the mean of all fertile hybrids (fertile single-crosses plus three-way crosses) differed significantly ($P = .01$) from that of the sterile single-crosses for grain yield, 100-seed weight and seeds/head, but not for heads/plant (Appendix Table 66). Significant differences ($P = .01$) between the fertile and sterile hybrids were observed in 1970 for grain yield and each of its components, including heads/plant (Appendix Table 67). When the 1969 and 1970 data were combined, significant differences ($P = .01$) were indicated only for grain yield and heads/plant (Table 6). Thus, the relationship between sterile and fertile hybrids was stable over years for grain yield and heads/plant but not for seeds/head or 100-seed

Table 22. Two-year means for grain yield and its primary components for sterile single-crosses, 1969 and 1970

Sterile single-cross	Character			
	Grain yield (g/plot)	100-seed weight (g)	Seeds/ head	Heads/ plant
A Kafir x B Martin	3264	2.86	1996	1.87
A Martin x B Kafir	3256	3.13	1699	1.75
A Kafir x B Wheatland	3472	3.05	2126	1.77
A Wheatland x B Kafir	3630	3.28	1784	1.77
A Kafir x B Redlan	3233	3.28	1644	1.67
A Redlan x B Kafir	3119	3.21	1853	1.60
A Martin x B Wheatland	3375	2.99	2085	1.62
A Wheatland x B Martin	3351	3.08	2025	1.85
A Martin x B Redlan	3145	3.02	2095	1.95
A Redlan x B Martin	3593	3.07	2191	1.60
A Wheatland x B Redlan	3548	3.31	1901	1.82
A Redlan x B Wheatland	3474	3.11	2103	1.65

weight.

The means for fertile and sterile hybrids for grain yield and its components are presented in Table 24. Sterile single-crosses consistently had lower yields, fewer seeds/head, and heads/plant than the fertile hybrids. The higher seed weight of sterile single-crosses was not surprising in view of their relatively low seed-set per plant. The significant interaction of sterile vs fertile hybrids with years for 100-seed weight and seeds/head (Table 6) seemed to result from a

Table 23. Analyses of variance for grain yield and yield components of sterile single-crosses for combined 1969 and 1970 experiments

Source of variation	Degrees of freedom	Mean squares			
		Grain yield	100-seed weight	Seeds/ head	Heads/ plant
Among sterile singles	11	119062	0.071	128808**	0.054
Reciprocals	6	81651	0.038	100864	0.068
g.c.a.	3	175428	0.138	203760	0.022
s.c.a.	2	146746	0.070	100212	0.060
Sterile singles x years	11	49121	0.044	26916	0.087
Reciprocals x years	6	22345	0.042	18856	0.038
g.c.a. x years	3	40760	0.038	47686	0.135
s.c.a. x years	2	141991	0.059	19941	0.162
Entries x years	87	72932	0.079	103516	0.105
Pooled error	174	47766	0.049	69203	0.076

Table 24. Means of sterile single-crosses and fertile single-crosses plus three-way crosses for grain yield and its components from individual and combined experiments, 1969 and 1970

Year and hybrid type	Character			
	Grain yield (g/plot)	100-seed weight (g)	Seeds/ head	Heads/ plant
1969				
Sterile singles	3265	3.19	1715	2.04
Fertile singles plus three-ways	3396	2.37	2337	2.15
Level of significance	**	**	**	ns
1970				
Sterile singles	3478	3.04	2202	1.50
Fertile singles plus three-ways	3618	2.62	2475	1.62
Level of significance	**	**	**	**
1969 and 1970				
Sterile singles	3372	3.12	1958	1.75
Fertile singles plus three-ways	3507	2.49	2406	1.89
Level of significance	**	ns	ns	**

convergence of means for the two groups in 1970. The difference between sterile and fertile hybrids for seed weight was only 12% in 1970 as compared with a difference of 34% in 1969. Similarly, the differences in seeds/head of sterile and fertile hybrids were 36% and 11% in 1969 and 1970, respectively.

Hybrids vs parents

The performance of hybrids and parents was compared to determine whether significant heterosis was expressed for the characters under study. The individual year data (Table 25, Appendix Tables 66 and 67) showed that significant heterosis was expressed for grain yield and seeds/head in both years, and for heads/plant in 1969. Heterosis was not manifested for 100-seed weight, with significantly higher seed weights shown by the parents in both years. The mean for all hybrids in 1969 exceeded that of the parents by 14.4% for grain yield, 11.3% for seeds/head, and 9.8% for heads/plant. In 1970 the percentage heterosis was 19.7 for yield and 22.0 for seeds/head, but the number of heads/plant was alike for the parents and hybrids.

The two-year means showed that the hybrids exceeded their parents in grain yield by 17.1%, in seeds/head by 16.6%, and in heads/plant by 4.7%. 100-seed weights were 6.0% higher for the parents in each year and for the two-year average. The combined analyses (Table 6) indicated that only the differences for grain yield and 100-seed weight were

Table 25. Group means for grain yield and its components in parents and hybrids, measured in individual and combined experiments, 1969 and 1970

Year and population type	Character			
	Grain yield (g/plot)	100-seed weight (g)	Seeds/ head	Heads/ plant
1969				
Parents	2950	2.65	2012	1.94
Hybrids	3375	2.49	2239	2.13
Level of significance	**	*	**	*
1970				
Parents	2999	2.85	1993	1.60
Hybrids	3589	2.68	2432	1.60
Level of significance	**	**	**	ns
1969 and 1970				
Parents	2975	2.75	2002	1.78
Hybrids	3485	2.59	2335	1.86
Level of significance	*	*	ns	ns

significant (P = .05). However, the test of parents vs hybrids for seeds/head was made with only one degree of freedom in both the numerator and denominator, and an F value of 161 was needed for significance at the 5% probability level. Thus, what seemed a marked difference between hybrids and parents in

seeds/head was classed as not significant.

The combined analyses also indicated that there was a significant hybrids vs parents x years interaction for grain yield, seeds/head and heads/plant. For both grain yield and seeds/head the interaction resulted from the parents as a group demonstrating remarkable stability for these traits over the two years, while the hybrids collectively showed appreciably higher means for both traits in 1970 (Table 25). The interaction for heads/plant seemed to result from the hybrids showing significant superiority over their parents in 1969, whereas means for the two groups were identical in 1970.

Comparisons among parents

Differences among the R-lines in 1969 were significant only for seeds/head (Appendix Table 66), with Plainsman and Caprock superior to both Tx 7078 and Redbine 60 for this trait (Table 21). In 1970 the R-lines differed significantly for yield and all of its primary components (Appendix Table 67), with Redbine 60 and Caprock being the highest in grain yield. Plainsman was the lowest yielding R-line in 1970, and it was also the lowest in 100-seed weight and heads/plant.

The A vs B-line comparison for grain yield was significant in 1970 but not in 1969 (Appendix Tables 67 and 66). This was true also for the (A + B) vs R-lines comparisons. In both years, significant differences were indicated for each of

these comparisons for 100-seed weight and seeds/head, but not for heads/plant. Usually, the B-lines had higher yields than the A-lines since the larger number of seeds/head of the B-lines more than compensated for their smaller seed size (Table 26). The A vs B-line comparison provides a test of cytoplasmic effects, since each A-line and its corresponding B-line have identical genotypes but different cytoplasms. However, the cytoplasmic effects were confounded to some degree with outcrossing ability of the sterile lines. Thus, seed set and, therefore, the performance of male-sterile types (A-lines) was, to a large extent, dependent on the amount, dispersion and viability of pollen available during the period of stigma receptivity.

The mean number of seeds/head of the R-lines in 1969 was significantly greater than that of the combined A and B lines, but their yields did not differ. Apparently, the advantage of the R-lines in number of seeds/head was just enough to offset the advantage of the A and B lines in 100-seed weight, since there was no difference between the groups in heads/plant. The high seed setting ability of the R-lines may reflect an indirect selection for large numbers of fertile florets that accompanied the selection for good pollen production during the development of these lines.

The performance of A-lines relative to B-lines did not change significantly from year to year (Table 27). The comparison of (A + B) vs R-lines, however, showed significant

Table 26. Group means for grain yield and its components for A, B and R-lines, 1969 and 1970

Group	Character and year							
	Grain yield (g/plot)		100-seed weight (g)		Seeds/head		Heads/plant	
	1969	1970	1969	1970	1969	1970	1969	1970
A-lines	2876	2780	3.21	3.34	1540	1570	1.84	1.64
B-lines	3004	3015	2.55	2.64	2106	2207	2.01	1.53
Level of significance	ns	*	**	**	**	**	ns	ns
A + B-lines	2940	2898	2.88	2.99	1823	1889	1.93	1.59
R-lines	2971	3202	2.19	2.57	2364	2201	1.94	1.63
Level of significance	ns	**	**	**	**	**	ns	ns

Table 27. Mean squares for A-lines vs B-lines, and A + B-lines vs R-lines comparisons and their interactions with years from combined 1969 and 1970 experiments

Comparison	Degrees of freedom	Mean squares			
		Grain yield	100-seed weight	Seeds/ head	Heads/ plant
A vs B-lines	1	263719	3.699*	2896228*	0.0003
A vs B-lines x years	1	22844	0.002	10260	0.1653
A + B-lines vs R-lines	1	300048*	3.308	1949115	0.0009
(A + B-lines vs R-lines) x years	1	200294*	0.182**	142219	0.0026
Entries x years	87	72932	0.079	103516	0.105
Pooled error	174	47766	0.049	69203	0.076

interaction with years for both grain yield and 100-seed weight. These interactions seem explicable in that means of the (A + B) lines remained relatively stable over years for both traits, but the R-lines showed distinctly higher means in 1970 than they did in 1969 (Table 26).

Correlations between grain yield and its components

Simple phenotypic correlations for grain yield with each of its components are presented in Table 28. Since yield components were measured in the spaced test, these correlations were calculated using yield per plot (10 plants) from the spaced test instead of yield data from the yield test.

The coefficients for grain yield with each of the yield components in the parents were not significantly different from zero. The only coefficient that approached the magnitude necessary for statistical significance (P = 0.05) in the parents was in 1970 for the relationship between grain yield and seeds/head.

Among the hybrids, highly significant correlations were observed, especially in correlations of yield with heads/plant and seeds/head. From the data presented in Table 28 it would appear that heads/plant was the most important yield-determining component studied and that 100-seed weight was the least important. However, there did appear to be differences in the relative importance of the various yield components in different hybrid types.

Table 28. Phenotypic correlation coefficients between grain yield and its components

Population type	Year	Degrees of freedom	Correlation of grain yield[a] with Heads/ plant	100-seed weight	Seeds/ head
Parents	1969	10	0.027	-0.034	0.019
	1970	10	0.181	-0.352	0.522
	1969 and 1970	10	0.296	0.317	0.182
Sterile singles	1969	10	0.578+	-0.136	0.735++
	1970	10	0.803++	-0.462	0.381
	1969 and 1970	10	0.593+	-0.355	0.737++
Fertile singles	1969	14	0.348	0.395	0.172
	1970	14	0.506+	0.213	0.500+
	1969 and 1970	14	0.216	0.302	0.563+
Three-way hybrids	1969	46	0.567++	0.135	-0.047
	1970	46	0.645++	0.267	-0.198
	1969 and 1970	46	0.552++	0.452++	-0.179

[a]Yield in this table refers to grain yield per plot (10 plants) in the spaced test.

+, ++ Signify significant differences from zero at the five and one percent probability levels, respectively.

In three-way crosses the relationship between grain yield and heads/plant was positive and highly significant (P = .01) in each of the individual years and when both years were combined. Grain yield in three-way hybrids was independent of seeds/head. The situation in fertile single-crosses contrasted sharply with this. In 1970, and when both years were combined, a significant positive correlation (P = .05) was found for grain yield and seeds/head in fertile single-crosses. Grain yield in the fertile single-crosses was independent of heads/plant in 1969 and when both years were combined. An additional point of contrast between the hybrid types was that when data were combined over years grain yield was significantly (P = .01), and positively, correlated with 100-seed weight in three-way crosses, whereas yield was largely independent of this component in fertile single-crosses.

Grain yield in sterile single-crosses was significantly correlated with both heads/plant and seeds/head when the data from both years were combined. In the individual years, both of these components were significantly correlated with yield in 1969, but only heads/plant was significantly correlated in 1970. In neither of the individual years, nor when both years were combined, did 100-seed weight prove to be significantly associated with grain yield.

Predictions of Grain Yields of Three-Way Crosses

The close similarity in general combining abilities for grain yield of the parental lines when measured in single-crosses and in three-way crosses, and the relative unimportance of specific combining ability effects suggested that accurate predictions of the yields of three-way crosses could be made from single-cross data. Furthermore, predictions based on parental performance per se would seem useful since specific combining ability effects for grain yield were shown to be minimal. To evaluate the effectiveness of predictions for yield of three-way crosses based on either single-cross or parental line yields, correlation coefficients describing the relationship between observed and predicted yields were calculated. These correlations and the observed and predicted yields of three-way hybrids are presented in Table 29. Highly significant ($P = .01$) correlations between the observed and predicted yields were obtained with both methods of prediction. A considerably closer relationship was shown, however, when single-cross data were used in accordance with Jenkins' Method B ($r = 0.70$) than when the predictions were based on parental performance per se ($r = 0.45$).

The effectiveness of the predictions based on Jenkins' Method B is illustrated in Table 30. If the ten highest yielding three-way hybrids (approximately 20% of the total) were selected on this basis, eight of the actual ten top

Table 29. Observed and predicted grain yields of three-way hybrids from combined 1969 and 1970 experiments

Three-way hybrid	Observed yield (g/plot)	Predicted yield (g/plot)	
		Jenkins' Method B	Parental performance method
(A K x B M) x Tx 7078	3474	3522	2901
(A M x B K) x Tx 7078	3421	3522	2901
(A K x B M) x Redbine 60	3390	3389	3021
(A M x B K) x Redbine 60	3618	3389	3021
(A K x B M) x Plainsman	3242	3278	2849
(A M x B K) x Plainsman	3208	3278	2849
(A K x B M) x Caprock	3717	3691	3110
(A M x B K) x Caprock	3574	3691	3110
(A K x B W) x Tx 7078	3727	3625	2829
(A W x B K) x Tx 7078	3352	3625	2829
(A K x B W) x Redbine 60	3554	3538	2949
(A W x B K) x Redbine 60	3388	3538	2949
(A K x B W) x Plainsman	3274	3372	2777
(A W x B K) x Plainsman	3278	3372	2777
(A K x B W) x Caprock	3550	3668	3038
(A W x B K) x Caprock	3758	3668	3038
(A K x B R) x Tx 7078	3950	3656	2872
(A R x B K) x Tx 7078	3677	3656	2872
(A K x B R) x Redbine 60	3672	3638	2992
(A R x B K) x Redbine 60	3538	3638	2992
(A K x B R) x Plainsman	3454	3490	2821
(A R x B K) x Plainsman	3583	3490	2821
(A K x B R) x Caprock	3718	3762	3081
(A R x B K) x Caprock	3795	3762	3081

A K = A Kafir 60 A R = A Redlan B W = B Wheatland
A M = A Martin B K = B Kafir 60 B R = B Redlan
A W = A Wheatland B M = B Martin

Table 29. (Continued)

Three-way hybrid	Observed yield (g/plot)	Predicted yield (g/plot)	
		Jenkins' Method B	Parental performance method
(A M x B W) x Tx 7078	3288	3458	2904
(A W x B M) x Tx 7078	3447	3458	2904
(A M x B W) x Redbine 60	3493	3455	3024
(A W x B M) x Redbine 60	3429	3455	3024
(A M x B W) x Plainsman	3107	3253	2853
(A W x B M) x Plainsman	3243	3253	2853
(A M x B W) x Caprock	3556	3630	3113
(A W x B M) x Caprock	3552	3630	3113
(A M x B R) x Tx 7078	3663	3489	2948
(A R x B M) x Tx 7078	3679	3489	2948
(A M x B R) x Redbine 60	3313	3555	3068
(A R x B M) x Redbine 60	3475	3555	3068
(A M x B R) x Plainsman	3395	3371	2896
(A R x B M) x Plainsman	3391	3371	2896
(A M x B R) x Caprock	3522	3724	3157
(A R x B M) x Caprock	3659	3724	3157
(A W x B R) x Tx 7078	3568	3592	2876
(A R x B W) x Tx 7078	3505	3592	2876
(A W x B R) x Redbine 60	3425	3704	2996
(A R x B W) x Redbine 60	3407	3704	2996
(A W x B R) x Plainsman	3204	3465	2824
(A R x B W) x Plainsman	3328	3465	2824
(A W x B R) x Caprock	3689	3701	3085
(A R x B W) x Caprock	3526	3701	3085
Correlation with observed yield --		0.703++	0.449++

++Significantly greater than zero at the one percent level of probability.

Table 30. Observed and predicted ranking of ten highest yielding three-way hybrids from combined 1969 and 1970 experiments

Rank for grain yield	Three-way cross	
	Observed	Predicted (Jenkins' Method B)
1	(A K x B R) x Tx 7078	(A K x B R) x Caprock
2	(A K x B R) x Caprock	(A M x B R) x Caprock
3	(A K x B W) x Caprock	(A W x B R) x Redbine 60
4	(A K x B W) x Tx 7078	(A W x B R) x Caprock
5	(A K x B M) x Caprock	(A K x B M) x Caprock
6	(A W x B R) x Caprock	(A K x B W) x Caprock
7	(A M x B R) x Tx 7078	(A K x B R) x Tx 7078
8	(A K x B R) x Redbine 60	(A K x B R) x Redbine 60
9	(A M x B R) x Caprock	(A M x B W) x Caprock
10	(A M x B K) x Redbine 60	(A K x B W) x Tx 7078

A K = A Kafir 60 B K = B Kafir 60
A M = A Martin B M = B Martin
A W = A Wheatland B W = B Wheatland
A R = A Redlan B R = B Redlan

hybrids would have been selected. It should be remembered, however, that this method of prediction does not take into account the possibility of reciprocal differences within the single-cross parents of three-way hybrids. If reciprocal effects were important the merit of the predictions could be affected adversely. Therefore, in order to determine the best

order for constituting the sterile single-cross parents of three-way crosses, 20 rather than 10 three-way hybrids would in fact have to be tested.

Plant Height and Days to Midbloom

Highly significant differences (P = .01) between entry means for plant height and days to midbloom were indicated in the combined analyses for the spaced test (Table 31). Although there was a wide range among individual entry means for days to midbloom, the difference between the earliest and latest entries was considerably less than the difference between years. The means over all entries in each year showed that the average number of days to midbloom was 11.4 days less in 1970 than in 1969 (72.3 vs 83.7 days). The latest entry, A Redlan, had a mean midbloom value for the two years of 82.5 days compared to 75.3 days for the earliest entries, which were A Kafir 60 x Tx 7078, a fertile single-cross, and (A Martin x B Kafir 60) x Plainsman, a three-way cross.

The difference between years also was significant for plant height with the mean for all entries being 17 cm less in 1970 than in 1969 (103 vs 120 cm). Plainsman was the shortest entry with a 2-year mean of 85 cm and the tallest was (A Redlan x B Kafir 60) x Redbine 60, a three-way cross, with a mean of 127 cm.

Homogeneity of the interactions of each component of the entries sums of squares with years was evaluated by

Table 31. Analyses of variance for days to midbloom and plant height for combined 1969 and 1970 experiments

Source of variation	Degrees of freedom	Mean squares	
		Days to midbloom	Plant height
Years	1	9069.78**	25515.52**
Replicates/years	2	4.27	36.68
Entries	87	11.86**	345.55**
Entries x years	87	3.95**	43.29**
Pooled error	174	2.40	15.07

Bartlett's test. For both characters, the tests indicated that the interactions were homogeneous. Tests of significance for each of the entry components, therefore, were made against the entries x years mean square in the combined analyses.

Single-crosses vs three-way crosses

The two-year means for fertile single-crosses and three-way hybrids as groups were virtually identical within each character (Table 32). The difference between the hybrid groups was only 0.2 for days to midbloom and 0.9 cm for plant height. Tests of the mean squares for the comparisons of fertile single-crosses vs three-way hybrids (Table 33) indicated that for both characters the two groups of hybrids were equivalent. For plant height, however, the relationship between fertile single-crosses and three-way hybrids was not stable over

Table 32. Group means and range of individual hybrid means for days to midbloom and plant height in fertile single-crosses and three-way hybrids from individual and combined experiments 1969 and 1970

Year and hybrid-type	Parameter	Days to midbloom	Plant height (cm)
1969			
Fertile single-crosses	Mean	82.2	121.2
	Range	79.3 - 85.0	98.9 - 139.1
Three-way hybrids	Mean	82.0	120.4
	Range	79.0 - 86.8	97.2 - 140.4
1970			
Fertile single-crosses	Mean	72.2	104.9
	Range	70.1 - 73.9	87.5 - 116.1
Three-way hybrids	Mean	72.0	102.7
	Range	69.4 - 74.6	85.1 - 115.7
1969 and 1970			
Fertile single-crosses	Mean	77.2	112.5
	Range	74.9 - 79.4	93.2 - 126.7
Three-way hybrids	Mean	77.0	111.6
	Range	74.5 - 80.5	93.5 - 126.8

years, as indicated by the significant interaction of this component with years. In 1969 these hybrid groups were equivalent statistically (Appendix Table 68) with a mean difference between them of only 0.8 cm (Table 32), but in 1970 (Appendix Table 69) a highly significant ($P = .01$) difference in height of the two groups was indicated by the analysis.

Table 33. Mean squares for hybrids vs parents and between hybrid-group comparisons for days to midbloom and plant height from analyses of combined 1969 and 1970 experiments

Source of variation	Degrees of freedom	Mean squares	
		Days to midbloom	Plant height
Hybrids vs parents	1	177.77**	1957.25**
Hybrids vs parents x years	1	0.13	200.44**
Fertile singles vs three-ways	1	1.00	38.97
Fertile singles vs three-ways x years	1	0.14	79.44*
Sterile singles vs (fertile singles + three-ways)	1	228.48**	25.62
Sterile singles vs (fertile singles + three-ways) x years	1	9.29	0.15
Entries x years	87	3.95**	43.29**
Pooled error	174	2.40	15.07

The mean difference in 1970, however, was only 2.2 cm (Table 32) which seems of minimal significance practically. In addition to the means for all fertile single-crosses and three-way crosses being similar, the range among means for the individual hybrids within each group also was similar (Table 32).

The major sources of variation for days to midbloom in the three-way crosses were those attributed to the variation among R-lines and among g.c.a. effects of parents of the

sterile single-crosses within three-way crosses (Table 34). In the fertile single-crosses, the only significant source of variation for midbloom was that for g.c.a. of the female parents (Table 35).

The g.c.a. effects of parental lines are presented respectively for days to midbloom and plant height in fertile single-crosses and three-way hybrids in Tables 36 and 37. The relative g.c.a. effects among parental lines for days to midbloom were similar when measured in either single-crosses or three-way hybrids, although a few shifts in ranking occurred. Usually, hybrids involving the Kafir 60 female or Plainsman male parent bloomed earlier than did the other hybrids (Tables 38 and 39). The latest hybrids were those with either Redlan or Redbine 60 in their parentage. Likewise, for plant height the g.c.a. effects of parental lines had similar rankings in both types of hybrids (Table 37). Hybrids having Wheatland as a female parent or Plainsman as a male parent generally were the shortest, and those involving Kafir 60, Redlan or Redbine 60 were tallest. With the exception of hybrids with Kafir 60 parentage there was some indication of a positive relationship between plant height and days to midbloom.

Differences attributable to s.c.a. effects of the hybrids were not significant for either character in fertile single-crosses or three-way hybrids (Tables 34 and 35). Neither were the differences due to reciprocal effects in the sterile single-cross parents of three-way crosses significant in any

Table 34. Analyses of variance for days to midbloom and plant height of three-way crosses from combined 1969 and 1970 experiments

Source of variation	Degrees of freedom	Mean squares	
		Days to midbloom	Plant height
Among three-way crosses	47	5.43	295.47**
R-lines	3	26.42**	3491.26**
Sterile singles	11	6.70	174.94**
Reciprocals	6	1.38	38.86
g.c.a.	3	20.10**	543.30**
s.c.a.	2	2.56	30.64
Sterile singles x R-lines	33	3.10	45.12
Reciprocals x R-lines	18	2.43	47.11
g.c.a. x R-lines	9	5.68	51.98
s.c.a. x R-lines	6	1.24	28.86
Three-way crosses x years	47	3.57*	37.19**
R-lines x years	3	10.14**	110.48**
Sterile singles x years	11	3.18	60.77**
Reciprocals x years	6	2.20	52.12**
g.c.a. x years	3	6.37	86.65**
s.c.a x years	2	1.34	47.90*
(Sterile singles x R-lines) x years	33	3.10	22.67
(Reciprocals x R-lines) x years	18	2.60	17.03
(g.c.a. x R-lines) x years	9	3.66	20.62
(s.c.a. x R-lines) x years	6	3.76	42.67*
Entries x years	87	3.95**	43.29**
Pooled error	174	2.40	15.07

Table 35. Analyses of variance for days to midbloom and plant height of fertile single-crosses from combined 1969 and 1970 experiments

Source of variation	Degrees of freedom	Mean squares	
		Days to midbloom	Plant height
Among fertile single-crosses	15	6.83*	461.33**
g.c.a. (females)	3	22.86**	582.35**
g.c.a. (males)	3	0.95	1506.94**
s.c.a.	9	3.45	71.38
Fertile single-crosses x years	15	3.41	43.89**
g.c.a. (females) x years	3	5.66	61.79**
g.c.a. (males) x years	3	2.07	63.12**
s.c.a. x years	9	3.11	31.44*
Entires x years	87	3.95**	43.29**
Pooled error	174	2.40	15.07

instance (Table 34), although the difference in plant height of nearly 10 cm between (A Martin x B Redlan) and its reciprocal in crosses with Redbine 60 (Table 39) seemed substantial. A reciprocal difference of similar magnitude was noted in crosses involving Wheatland, Redlan and Redbine 60.

Table 36. General combining ability effects for days to mid-bloom of parental lines in fertile single-crosses and three-way crosses from combined 1969 and 1970 experiments

Parental line	General combining ability effects	
	Fertile single-crosses	Three-way crosses
Female		
Kafir 60	-1.60	-1.18
Martin	-0.11	-0.28
Wheatland	0.51	-0.03
Redlan	1.21	1.48
Male		
Tx 7078	0.12	-0.56
Redbine 60	0.29	0.84
Plainsman	-0.17	-0.67
Caprock	-0.23	0.42

Table 37. General combining ability effects for plant height of parental lines in fertile single-crosses and three-way crosses from combined 1969 and 1970 experiments

Parental line	General combining ability effects	
	Fertile single-crosses	Three-way crosses
Female		
Kafir 60	2.32	3.29
Martin	-0.39	2.69
Wheatland	-8.11	-8.74
Redlan	6.15	2.76
Male		
Tx 7078	1.56	0.33
Redbine 60	8.42	6.57
Plainsman	-13.92	-12.13
Caprock	3.94	5.26

Table 38. Means of fertile single-crosses for days to midbloom and plant height from combined 1969 and 1970 experiments

Fertile single-cross	Days to midbloom	Plant height (cm)
Kafir 60 x Tx 7078	74.9	121.6
x Redbine 60	76.1	124.4
x Plainsman	75.3	96.9
x Caprock	75.9	116.2
Martin x Tx 7078	77.9	107.0
x Redbine 60	76.4	122.1
x Plainsman	76.8	101.9
x Caprock	77.1	117.4
Wheatland x Tx 7078	78.2	103.5
x Redbine 60	79.4	110.3
x Plainsman	76.9	93.2
x Caprock	76.3	110.4
Redlan x Tx 7078	78.2	124.0
x Redbine 60	77.9	126.7
x Plainsman	78.9	102.2
x Caprock	78.5	121.5

Table 39. Means of three-way crosses for days to midbloom and plant height from combined 1969 and 1970 experiments

Three-way hybrid	Days to midbloom	Plant height (cm)
(A K x B M) x Tx 7078	75.0	115.5
(A M x B K) x Tx 7078	76.6	115.4
(A K x B M) x Redbine 60	77.7	119.6
(A M x B K) x Redbine 60	76.4	119.1
(A K x B M) x Plainsman	76.6	100.0
(A M x B K) x Plainsman	75.8	101.3
(A K x B M) x Caprock	76.8	118.8
(A M x B K) x Caprock	77.4	121.8
(A K x B W) x Tx 7078	75.3	110.0
(A W x B K) x Tx 7078	76.3	110.8
(A K x B W) x Redbine 60	76.6	116.3
(A W x B K) x Redbine 60	78.0	115.8
(A K x B W) x Plainsman	76.7	93.5
(A W x B K) x Plainsman	75.6	95.8
(A K x B W) x Caprock	75.6	112.9
(A W x B K) x Caprock	76.5	114.4
(A K x B R) x Tx 7078	76.0	119.6
(A R x B K) x Tx 7078	76.8	116.8
(A K x B R) x Redbine 60	77.4	121.5
(A R x B K) x Redbine 60	78.4	126.8
(A K x B R) x Plainsman	75.1	101.0
(A R x B K) x Plainsman	75.3	102.3
(A K x B R) x Caprock	78.8	115.9
(A R x B K) x Caprock	78.5	118.7

A K = A Kafir 60	B K = B Kafir 60
A M = A Martin	B M = B Martin
A W = A Wheatland	B W = B Wheatland
A R = A Redland	B R = B Redlan

Table 39. (Continued)

Three-way hybrid	Days to midbloom	Plant height (cm)
(A M x B W) x Tx 7078	77.6	110.4
(A W x B M) x Tx 7078	76.2	105.1
(A M x B W) x Redbine 60	77.0	117.7
(A W x B M) x Redbine 60	77.1	117.1
(A M x B W) x Plainsman	76.2	100.0
(A W x B M) x Plainsman	77.4	93.7
(A M x B W) x Caprock	75.8	113.0
(A W x B M) x Caprock	76.3	117.2
(A M x B R) x Tx 7078	76.0	115.2
(A R x B M) x Tx 7078	77.3	111.3
(A M x B R) x Redbine 60	78.0	112.4
(A R x B M) x Redbine 60	78.8	121.2
(A M x B R) x Plainsman	76.5	102.4
(A R x B M) x Plainsman	77.3	108.5
(A M x B R) x Caprock	78.6	117.7
(A R x B M) x Caprock	77.9	124.4
(A W x B R) x Tx 7078	76.8	103.3
(A R x B W) x Tx 7078	77.6	109.1
(A W x B R) x Redbine 60	80.5	120.6
(A R x B W) x Redbine 60	78.4	109.3
(A W x B R) x Plainsman	76.6	99.3
(A R x B W) x Plainsman	77.1	95.2
(A W x B R) x Caprock	79.0	110.3
(A R x B W) x Caprock	78.1	116.6

A lines vs sterile single-crosses

The two-year means for days to midbloom and plant height along with the range of individual entry means (Table 40) showed that the A-lines and sterile single-crosses were very much alike for these traits. Sterile single-crosses reached midbloom a half-day sooner and they were less than 3 cm taller than the sterile lines. In view of the closeness of the means for the two groups, statistical tests of the significance of the difference between the means were not made since the differences certainly are of little practical significance. The ranges of means for individual entries within each group were nearly alike for days to midbloom (Table 40), but the A-lines showed a wider range in plant height than did the sterile single-crosses. The shortest A-line (A Wheatland) had a mean plant height of 95 cm (Table 41), whereas the shortest sterile single-cross (A Wheatland x B Kafir 60) had a mean of 104 cm.

An advantage for sterile single-crosses relative to A-lines in terms of stability over years was not shown for either midbloom or plant height since significant interactions with years were indicated for both groups (Table 42). As shown previously for sterile single-crosses within the three-way hybrids, reciprocal effects were not a source of significant variation within the sterile singles per se, and this absence of reciprocal effects was consistent over years (Table 42).

Table 40. Group means for A-lines and sterile single-crosses, and range of individual means within each group, for days to midbloom and plant height from combined 1969 and 1970 experiments

Population type	Parameter	Days to midbloom	Plant height (cm)
A-lines	Mean	80.0	109.9
	Range	78.0 - 82.1	94.7 - 117.6
Sterile single-crosses	Mean	79.5	112.6
	Range	76.8 - 81.2	103.7 - 118.0

Table 41. Means of parental lines for days to midbloom and plant height, 1969 and 1970

	Days to midbloom			Plant height (cm)		
Parental line	1969	1970	1969 & 1970	1969	1970	1969 & 1970
A Kafir 60	84	72	78	126	105	115
A Martin	84	72	78	120	104	112
A Wheatland	85	78	82	98	91	95
A Redlan	86	78	82	132	103	118
Mean of A-lines	85	75	80	119	101	110
B Kafir 60	84	73	78	120	101	111
B Martin	83	72	77	118	105	111
B Wheatland	85	76	81	99	91	95
B Redlan	85	80	83	136	105	121
Mean of B-lines	84	75	80	118	101	110
R Tx 7078	85	72	79	104	88	96
R Redbine 60	84	72	78	129	111	120
R Plainsman	83	73	78	86	83	85
R Caprock	86	76	81	114	96	105
Mean of R-lines	85	73	79	108	95	101

Table 42. Analyses of variance for days to midbloom and plant height in A-lines and sterile single-crosses from combined 1969 and 1970 experiments

Source of variation	Degrees of freedom	Mean squares	
		Days to midbloom	Plant height
Among A-lines	3	17.86**	430.9**
A-lines x years	3	9.15*	87.7**
Among sterile single-crosses	11	8.71*	190.6**
Reciprocals	6	4.99	42.0
g.c.a.	3	18.00**	614.2**
s.c.a.	2	5.94	0.8
Sterile single-crosses x years	11	4.10	46.4**
Reciprocals x years	6	1.84	24.9
g.c.a. x years	3	9.54**	101.7**
s.c.a. x years	2	2.72	27.9
Entries x years	87	3.95**	43.3**
Pooled error	174	2.40	15.1

Sterile vs fertile hybrids

The comparison of sterile single-crosses vs the mean of fertile single-crosses plus three-way crosses (Table 33) was significant (P = .01) for days to midbloom, but not for plant height. Furthermore, the relationship between the sterile and fertile hybrids was stable over years, as shown by the lack of significance for the interaction of this comparison with years (Table 33). The two-year mean for days to midbloom was 79.5

in sterile single-crosses and 77.1 in the fertile hybrids. Mean plant heights were nearly identical for the two groups, 112.6 cm in sterile hybrids and 111.8 cm in the fertiles.

Hybrids vs parents

Significant heterosis (P = .01) was expressed for both days to midbloom and plant height (Table 33), with hybrids being earlier blooming and taller than parents. The hybrids reached midbloom in 77.4 days, but the parents needed 80 days to reach this stage (two-year means). This relationship was consistent over years (Table 33). Mean plant height for the two years was 107 cm for the parents and 113 cm for the hybrids. The combined analysis for plant height (Table 33) did indicate, however, that there was a significant interaction of the parents vs hybrids comparison with years.

Comparisons among parents

In the combined analyses (Table 43) significant differences (P = .01) among A-lines were indicated for both days to midbloom and plant height. The two-year means in Table 41 show that A Kafir 60 and A Martin were four days earlier in blooming than A Wheatland and A Redlan. However, the individual-year means for each A-line (Table 41) and the individual-year analyses (Appendix Tables 68 and 69) showed that the difference between these pairs of A-lines was considerably greater in 1970 than in 1969, the differences being 6.0 and 1.5 days, respectively. This could account for the significant inter-

Table 43. Mean squares for variation among and between parental types from combined 1969 and 1970 experiments

Source of variation	Degrees of freedom	Mean squares	
		Days to midbloom	Plant height
A-lines	3	17.86**	430.9**
A-lines x years	3	9.15*	87.7**
B-lines	3	23.08**	460.1**
B-lines x years	3	8.54*	102.2**
R-lines	3	7.05	885.9**
R-lines x years	3	2.82	48.1*
A vs B-lines	1	0.10	0.2
A vs B-lines x years	1	0.09	0.3
(A + B) lines vs R-lines	1	0.21	92.2
(A + B) lines vs R-lines x years	1	2.48	6.4
Entries x years	87	3.95**	43.3**
Pooled error	174	2.40	15.1

action of A-lines with years noted in the combined analysis (Table 43). The tallest A-line was Redlan and Wheatland was the shortest (Table 41). In the individual years Wheatland maintained its position as the shortest A-line, but the ranking of the other lines changed from year to year, again contributing to the significant interaction of A-lines x years shown in Table 43.

The relative performance among B-lines for days to midbloom and plant height was essentially like that discussed for the A-lines (Tables 41 and 43). The comparison of A-lines vs B-lines, therefore, was not significant in either the individual (Appendix Tables 68 and 69) or combined year analyses (Table 43) for either character. These comparisons indicated that the presence of male-sterility inducing vs normal cytoplasm in the lines did not have a significant effect on performance of the lines for days to midbloom or plant height.

Among the R-lines there were no significant differences for days to midbloom when data for both years were combined (Table 43). However, in 1970 highly significant differences among R-lines were noted for days to midbloom (Appendix Table 69). In that year Caprock bloomed considerably later than did the other R-lines (Table 41). Highly significant differences ($P = .01$) between mean plant heights of the R-lines were indicated by the combined analysis (Table 43). Redbine 60 was the tallest (120 cm) and Plainsman the shortest (85 cm) of the R-lines (Table 41). A similar ranking for height of the R-

lines was found in each of the individual years, and the differences again were highly significant (Appendix Tables 68 and 69). The interaction of R-lines with years (Table 43) was significant, however, because the range of means for the individual R-lines was much greater in 1969 than in 1970 (Table 41).

Although there were significant differences in plant height between means of the R-lines vs those of A plus B-lines in the individual years (Appendix Tables 68 and 69), the combined-year data showed that the two groups of lines were statistically equivalent (Table 43). The combined analysis (Table 43) showed a similar result for days to midbloom in the two groups of lines.

Within-plot Variability

Within-plot standard deviations for each character were calculated from the data recorded on 10 plants in each plot in the spaced test in both years. These standard deviations were then analyzed in the same manner as described for plot means of the yield test in the Materials and Methods section. Although the main interest was in variability for plant height and days to midbloom, the variability data for grain yield and its components also will be presented.

Tables 44 and 45 show the combined analyses for variability in plant height and days to midbloom and for grain yield and its components. They show that differences between

Table 44. Analysis of variance of within-plot standard deviations for plant height and days to midbloom from combined 1969 and 1970 experiments

Source of variation	Degrees of freedom	Mean squares	
		Plant height	Days to midbloom
Years	1	511.45	5.55
Replications/years	2	8.35	3.36**
Entries	87	20.45**	1.02**
Entries x years	87	8.94	0.50
Error	174	7.74	0.44

years were insignificant for each character, and that in only one instance (100-seed weight) was there a significant interaction between entries and years. Significant differences in within-plot variability between entries were indicated for plant height, days to midbloom, grain yield, and heads/plant, but not for 100-seed weight and seeds/head.

Single-crosses vs three-way crosses

Table 46 shows mean squares and levels of significance for comparisons of interest between hybrid types and between parents and hybrids for variability in plant height and days to midbloom. Highly significant differences (P = .01) were indicated between fertile single-crosses and three-way crosses for both characters, and the relationship between these hybrid

Table 45. Analysis of variance of within-plot standard deviations for grain yield and its components from combined 1969 and 1970 experiments

Source of variation	Degrees of freedom	Mean squares			
		Grain yield	100-seed weight	Heads/ plant	Seeds/ head
Years	1	2373.8	0.026	0.913	570746
Replications/years	2	262.0	0.004	0.067	29666
Entries	87	150.3*	0.015	0.045**	28130
Entries x years	87	109.0	0.014*	0.038	17296
Error	174	109.9	0.009	0.029	28614

types was consistent over years. Mean within-plot standard deviations for plant height and days to midbloom of fertile single-crosses and three-way crosses are shown for each year, and for the results combined over years, in Table 47. In all comparisons the three-way crosses, as a group, were more variable for both characters than the fertile single-crosses.

The possibility that some three-way crosses might be as uniform as the most uniform single-cross was investigated by comparing the ranges of within-plot standard deviations observed for individual hybrids within both groups (Table 47). In both years, either individually or combined, the most uniform three-way cross was more variable for height and midbloom than the most uniform single-cross. At the other end of the scale, the single-cross most variable for either

Table 46. Mean squares and levels of significance for comparisons among hybrid types and between hybrids and parents for variability in plant height and days to midbloom from combined 1969 and 1970 experiments

Source of variation	Degrees of freedom	Mean squares	
		Plant height	Days to midbloom
Fertile singles vs three-ways	1	154.35**	10.64**
(Fertile singles vs three-ways) x years	1	0.60	0.64
Sterile singles vs (fertile singles plus three-ways)	1	138.91**	1.29
(Sterile singles vs fertile singles plus three-ways) x years	1	40.52*	7.46**
Hybrids vs parents	1	64.19**	0.14
(Hybrids vs parents) x years	1	10.60	0.18
Pooled error	174	7.74	0.44

character was more uniform than the most variable three-way cross. Nevertheless, for both traits, several of the three-way hybrids showed levels of variability below that observed for the single-crosses as a group (Tables 47 and 48). In fact, over the two-year period, one-fourth of the three-way hybrids had mean within-plot standard deviations for plant height equivalent to, or less than, the mean for fertile single-crosses. A similar pattern was noted in the variability

Table 47. Means and ranges of within-plot standard deviations for plant height and days to midbloom in fertile single-crosses and three-way crosses, measured in 1969 and 1970 and combined over both years

Year and population type	Parameter	Standard deviations: Plant height (cm)	Standard deviations: Days to midbloom
1969			
Fertile single-crosses	Mean	8.8	2.2
	Range	5.6 - 16.8	1.3 - 3.5
Three-way crosses	Mean	10.7	2.7
	Range	7.0 - 19.6	1.4 - 3.7
1970			
Fertile single-crosses	Mean	6.1	1.8
	Range	3.7 - 8.0	0.9 - 2.5
Three-way crosses	Mean	7.8	2.3
	Range	4.3 - 13.3	1.4 - 4.1
1969 and 1970			
Fertile single-crosses	Mean	7.4	2.0
	Range	5.5 - 12.4	1.4 - 2.8
Three-way crosses	Mean	9.2	2.5
	Range	6.1 - 16.1	1.5 - 3.6

for days to midbloom. However, the usefulness of this variability from a selection standpoint is greatly lessened by the fact that those three-way hybrids that were most uniform for plant height were not the hybrids most uniform for days to midbloom.

Table 48. Mean within-plot standard deviations for plant height and days to midbloom in three-way crosses, from combined 1969 and 1970 experiments

Three-way hybrid	Standard deviations: Plant height (cm)	Standard deviations: Days to midbloom
(A K x B M) x Tx 7078	9.6	2.7
(A M x B K) x Tx 7078	11.2	2.2
(A K x B M) x Redbine 60	9.1	2.7
(A M x B K) x Redbine 60	11.6	1.9
(A K x B M) x Plainsman	8.2	1.6
(A M x B K) x Plainsman	7.7	1.8
(A K x B M) x Caprock	11.2	2.1
(A M x B K) x Caprock	9.5	1.5
(A K x B W) x Tx 7078	11.1	2.6
(A W x B K) x Tx 7078	9.1	2.7
(A K x B W) x Redbine 60	11.0	3.1
(A W x B K) x Redbine 60	9.8	2.5
(A K x B W) x Plainsman	8.0	2.4
(A W x B K) x Plainsman	9.8	2.4
(A K x B W) x Caprock	8.4	2.4
(A W x B K) x Caprock	10.6	2.5
(A K x B R) x Tx 7078	8.2	2.7
(A R x B K) x Tx 7078	10.3	2.5
(A K x B R) x Redbine 60	12.4	2.9
(A R x B K) x Redbine 60	13.8	3.3
(A K x B R) x Plainsman	9.1	2.1
(A R x B K) x Plainsman	9.8	1.9
(A K x B R) x Caprock	11.6	2.5
(A R x B K) x Caprock	9.3	3.4
(A M x B W) x Tx 7078	7.4	2.5
(A W x B M) x Tx 7078	7.2	2.6
(A M x B W) x Redbine 60	6.6	3.2
(A W x B M) x Redbine 60	6.5	3.0
(A M x B W) x Plainsman	6.1	2.4
(A W x B M) x Plainsman	8.3	2.0

A K = A Kafir 60 — B K = B Kafir 60
A M = A Martin — B M = B Martin
A W = A Wheatland — B W = B Wheatland
A R = A Redlan — B R = B Redlan

Table 48. (Continued)

Three-way hybrid	Standard deviations: Plant height (cm)	Standard deviations: Days to midbloom
(A M x B W) x Caprock	8.3	2.8
(A W x B M) x Caprock	8.9	3.1
(A M x B R) x Tx 7078	7.8	2.8
(A R x B M) x Tx 7078	10.6	3.6
(A M x B R) x Redbine 60	16.1	2.3
(A R x B M) x Redbine 60	6.9	3.0
(A M x B R) x Plainsman	6.2	2.3
(A R x B M) x Plainsman	7.0	2.0
(A M x B R) x Caprock	6.5	2.8
(A R x B M) x Caprock	9.8	2.6
(A W x B R) x Tx 7078	8.7	2.5
(A R x B W) x Tx 7078	6.3	1.7
(A W x B R) x Redbine 60	6.8	1.9
(A R x B W) x Redbine 60	14.1	2.2
(A W x B R) x Plainsman	6.8	2.1
(A R x B W) x Plainsman	7.8	1.5
(A W x B R) x Caprock	10.3	3.0
(A R x B W) x Caprock	10.0	2.1

To evaluate the desirability of selecting relatively uniform three-way hybrids simple correlations between grain yield and the level of variability for each character other than grain yield were calculated. A significant ($P = .05$) positive correlation between grain yield of three-way hybrids and variability for days to midbloom is shown in Table 49, indicating that selection of three-way hybrids uniform for days to midbloom would result in simultaneous selection of lower yielding types. On the other hand, selection of three-way

Table 49. Simple correlation coefficients describing relationships between grain yields and within-plot standard deviations, in fertile single-crosses and three-way crosses, for each character measured in the combined 1969 and 1970 experiments

Correlation of grain yield with standard deviation for:	Correlation coefficients	
	Fertile single-crosses	Three-way crosses
Plant height	0.051	0.114
Days to midbloom	-0.573+	0.288+
Grain yield	0.658+	0.463++
100-seed weight	-0.273	-0.359++
Heads/plant	-0.099	0.149
Seeds/head	-0.081	-0.409++
Degrees of freedom	14	46

+Significantly different from zero at the five percent level of probability.

++Significantly different from zero at the one percent level of probability.

hybrids showing uniformity in height should have no detrimental effect on grain yield. Likewise, among the fertile single-crosses grain yield and variability for plant height were unrelated (Table 49). But, in contrast to the three-way crosses, a significant negative relationship was found between grain yield of the single-crosses and variability for days to midbloom, indicating that the highest yielding single-crosses

also were the most uniform for days to midbloom.

The association of grain yield with plant to plant variability for yield and its components seems of markedly less consequence practically than the relationship of yield with variability for height and midbloom. The correlations in Table 49 do indicate, however, that the single- and three-way crosses most variable for individual plant yield were the highest yielding. Among the three-way crosses significant negative relationships were indicated between grain yield and the variability for 100-seed weight and seeds/head.

Within-hybrid variability in a three-way cross might be attributed to either one, or both, of two causes, namely, differences between parents of the sterile single-cross for that character, or heterogeneity in any of the three parental lines. If the predominant cause of high variability in three-way crosses was a pronounced difference between parents in the sterile single-crosses, three-way crosses showing excessive variability could be avoided by not combining unlike parents in the sterile single-crosses. Simple correlation coefficients quantifying the degree of association between within-plot variability of three-way crosses and the difference between the parents of sterile single-crosses are presented for plant height and days to midbloom in Table 50. The coefficients for plant height were not significantly different from zero in either year or when both years were combined. For days to midbloom there was a significant positive relationship in 1970

Table 50. Simple correlation coefficients describing relationships between within-plot variability of three-way crosses and differences between parents of sterile single-crosses, from individual experiments and from combined 1969 and 1970 experiments

Character	Degrees of freedom	Correlation coefficients		
		1969	1970	1969 & 1970
Plant height	10	0.264	-0.366	-0.458
Days to midbloom	10	0.228	0.593+	0.439

+Significantly different from zero at the five percent level of probability.

but not in 1969. When both years were combined, the correlation coefficient was not significantly different from zero.

The other cause to which within-hybrid variability might be attributed (heterogeneity in parental lines) was investigated by examining the levels of variability within parental lines per se and within the same lines in hybrid combinations. Genetic heterogeneity in parental lines, in addition to creating variability in three-way crosses, should also cause plant-to-plant variation in single-crosses. Table 51 presents the mean within-plot standard deviations for plant height and days to midbloom for A-lines and R-lines per se, and for A-lines averaged over all R-lines and R-lines averaged over all A-lines in fertile single-crosses. If genetic heterogeneity was a major cause of variation within single crosses, the

Table 51. Mean within-plot standard deviations for plant height and days to midbloom of parental lines *per se* and of parental lines in fertile single-crosses, from combined 1969 and 1970 experiments

	Mean standard deviations			
	Plant height		Days to midbloom	
Parental line	Parental line	Fertile single-cross	Parental line	Fertile single-cross
A Kafir 60	10.1	7.8	2.67	1.95
A Martin	5.5	7.4	1.87	2.26
A Wheatland	4.0	6.7	2.32	2.03
A Redlan	8.8	7.9	2.37	1.78
Level of significance	**	ns	ns	ns
R Tx 7078	7.2	6.2	2.22	1.94
R Redbine 60	8.0	7.8	1.65	2.20
R Plainsman	7.7	7.2	2.47	2.16
R Caprock	7.5	8.5	2.37	1.72
Level of Significance	ns	ns	ns	ns

ranking of A-lines and R-lines should be the same in hybrids as in lines *per se*. Rankings of the lines (Table 51) were markedly dissimilar for both characters, however, suggesting that genetic heterogeneity was not a major factor in creating within-hybrid variability in fertile single-crosses. Table 52

Table 52. Mean within-plot standard deviations for plant height and days to midbloom of parental lines *per se*, and of parental lines in three-way crosses, from combined 1969 and 1970 experiments

	Mean standard deviations			
	Plant height		Days to midbloom	
Parental line	Parental line	Three-way cross	Parental line	Three-way cross
A Kafir 60	10.1	9.8	2.67	2.48
A Martin	5.5	7.9	1.87	2.35
A Wheatland	4.0	8.6	2.32	2.52
A Redlan	8.8	9.6	2.37	2.48
Level of significance	**	**	ns	ns
B Kafir 60	7.6	10.2	2.60	2.38
B Martin	6.2	8.6	1.77	2.58
B Wheatland	4.5	8.8	2.27	2.40
B Redlan	9.5	9.2	2.65	2.49
Level of significance	ns	**	ns	ns
R Tx 7078	7.2	9.0	2.22	2.59
R Redbine 60	8.0	10.4	1.65	2.66
R Plainsman	7.7	7.9	2.47	2.04
R Caprock	7.5	9.5	2.37	2.56
Level of significance	ns	**	ns	**

shows the same comparison in three-way crosses. The data for plant height indicated that there was some association between the level of variability for plant height within a particular A-line and the level of variability within three-way hybrids involving that A-line. It seemed, however, that the variability of three-way crosses for days to midbloom was not predictable from the within-plot variability data for parental lines.

The difficulty surrounding the prediction of within-hybrid variability of three-way crosses for either plant height or days to midbloom might be expected from the analyses of the data for variability of three-way crosses for these characters (Table 53). The analysis for each character showed that differences between three-way crosses, in terms of within-hybrid variability, were to a significant extent due to the effects of specific combinations of parents, in addition to the general effects of parental lines.

When fertile single-crosses and three-way crosses were compared with respect to within-hybrid variability for grain yield and each of its components the plant-to-plant variation in fertile single-crosses was no different from that in three-way crosses, except for heads/plant (Table 54). In fact, this one instance of significant difference between the single- and three-way crosses was one in which the variability within three-way crosses was significantly less than that of single-crosses. The ranges among means for the individual hybrids

Table 53. Analyses of variance of within-plot standard deviation for plant height and days to midbloom in three-way crosses, from combined 1969 and 1970 experiments

Source of variation	Degrees of freedom	Mean squares	
		Plant height	Days to midbloom
Among three-way crosses	47	19.49**	0.989**
R-lines	3	52.83**	4.000**
Sterile single crosses	11	19.32**	1.610**
Reciprocals	6	3.97*	0.754
g.c.a.	3	61.56**	0.039
s.c.a	2	2.00	6.535**
Sterile singles x R-lines	33	16.51**	0.508
Reciprocals x R-lines	18	21.82**	0.449
g.c.a. x R-lines	9	12.07	0.531
s.c.a. x R-lines	6	7.27	0.651
Three-way crosses x years	47	10.07	0.429
R-lines x years	3	6.69	0.280
Sterile single-crosses x years	11	5.79	0.294
Reciprocals x years	6	2.88	0.261
g.c.a. x years	3	4.28	0.531
s.c.a. x years	2	16.78	0.038
(Sterile singles x R-lines) x years	33	11.81*	0.488
(Reciprocals x R-lines) x years	18	13.81**	0.515
(g.c.a. x R-lines) x years	9	8.21	0.625
(s.c.a. x R-lines) x years	6	11.20	0.202
Pooled error	174	7.74	0.44

Table 54. Mean squares and levels of significance for comparisons among hybrid types and between hybrids and parents for variability in grain yield, and yield components, from combined 1969 and 1970 experiments

Source of variation	Degrees of freedom	Mean squares			
		Grain yield	100-seed weight	Heads/ plant	Seeds/ head
Fertile single-crosses vs three-way crosses	1	113.5	0.042	0.155*	12773
(Fertile singles vs three-ways) x years	1	0.5	0.074	0.073	6936
Sterile single-crosses vs fertile singles plus three-ways	1	1463.0**	0.071*	0.230**	245167**
(Sterile singles vs fertile singles plus three-ways) x years	1	159.9	0.069	0.036	1566
Parents vs hybrids	1	1488.0**	0.025	0.011	75318
(Parents vs hybrids) x years	1	141.8	0.004	0.004	82277
Entires x years	87	109.0	0.014*	0.038	17296
Pooled error	174	109.9	0.009	0.029	28614

within each hybrid group (Table 55) show that the range was quite similar in both groups for all characters. Correlation coefficients describing the relationship between yields of three-way crosses and levels of variability for yield components showed that a significant negative relationship existed between grain yield and variability for both 100-seed weight and seeds/head (Table 49), but the correlation between grain yield and variability for heads/plant was not significant. These results indicate that selection of high yielding three-way crosses would not effect the within-hybrid variability for heads/plant, and would in fact reduce variability for 100-seed weight and seeds/head.

A-lines vs sterile single-crosses

Generally there was very little difference between the A-lines and sterile single-crosses in mean within-plot standard deviations for plant height and days to midbloom (Table 56). More often than not the variability within sterile single-crosses for these characters was somewhat less than that observed within A-lines. Table 57, which shows the mean squares and results of tests of significance for these comparisons, indicates that the observed differences lay within the limits of experimental error, and that the relationship between these population types was stable over years.

Table 56 also indicates that the range of individual means was reasonably similar in both groups for each character.

Table 55. Mean and range of within-plot standard deviations for grain yield and yield components in fertile single-crosses and three-way crosses, measured in 1969 and 1970 and combined over both years

Year and hybrid-type	Parameter	Standard deviations			
		Grain yield (g/plot)	100-seed weight (g)	Heads/plant	Seeds/head
1969					
Fertile single-crosses	Mean	46.5	0.34	0.84	545
	Range	37.4 - 60.4	0.17 - 0.49	0.52 - 1.13	447 - 660
Three-way crosses	Mean	44.8	0.33	0.82	574
	Range	30.3 - 69.9	0.14 - 0.60	0.60 - 1.02	367 - 834
1970					
Fertile single-crosses	Mean	41.0	0.26	0.81	654
	Range	30.6 - 52.8	0.16 - 0.36	0.56 - 1.07	481 - 874
Three-way crosses	Mean	39.6	0.32	0.71	658
	Range	20.1 - 54.1	0.21 - 0.49	0.35 - 1.06	371 - 881
1969 and 1970					
Fertile single-crosses	Mean	43.8	0.30	0.82	600
	Range	34.9 - 55.0	0.19 - 0.39	0.65 - 1.10	480 - 702
Three-way crosses	Mean	42.2	0.33	0.77	616
	Range	30.9 - 58.3	0.22 - 0.49	0.51 - 0.99	456 - 780

Table 56. Mean within-plot standard deviations and range of individual means for plant height and days to midbloom of A-lines and sterile single-crosses, measured in 1969 and 1970 and combined over both years

Year and population type	Parameter	Standard deviations: Plant height (cm)	Standard deviations: Days to midbloom
1969			
A-lines	Mean	8.0	2.2
	Range	4.3 - 12.8	1.5 - 3.1
Sterile single-crosses	Mean	7.4	2.0
	Range	4.6 - 10.8	1.2 - 3.6
1970			
A-lines	Mean	6.2	2.4
	Range	3.7 - 8.6	2.2 - 2.5
Sterile single-crosses	Mean	6.5	2.4
	Range	3.1 - 11.7	1.2 - 3.9
1969 and 1970			
A-lines	Mean	7.2	2.3
	Range	4.0 - 10.1	1.9 - 2.7
Sterile Single-crosses	Mean	6.9	2.2
	Range	5.0 - 9.4	1.3 - 3.4

Least significant differences (P = .05), calculated for plant height and days to midbloom from the combined analyses, were 3.9 cm and 0.9 days, respectively. When the data from both years were combined the differences between the most uniform types within each group did not exceed the LSD .05 for either character. Also, the least uniform A-line did not differ significantly from the least uniform sterile single-cross for

Table 57. Mean squares and levels of significance for single-degree-of-freedom comparison of A-lines and sterile single-crosses for within-plot standard deviations, from combined 1969 and 1970 experiments

Character	Mean squares	
	A-lines vs sterile single-crosses	A-lines vs sterile single-crosses x years
Plant height	0.500 ns	1.650 ns
Days to midbloom	0.207 ns	0.278 ns
Grain yield	305.273 ns	31.769 ns
100-seed weight	0.011 ns	0.010 ns
Heads/plant	0.006 ns	0.022 ns
Seeds/head	6972 ns	50343 ns

either character.

The levels of variability for grain yield and each of the yield components were statistically equivalent in A-lines and sterile single-crosses (Table 57), with no indication of significant interaction with years. Mean within-plot standard deviations of the A-lines and sterile single-crosses, as groups, and the ranges of individual means within each group, for yield-related characters are presented in Table 58. Least significant differences ($P = .05$) for individual hybrid means, calculated from the combined analyses, were 14.7 g, 0.17 g, 0.24, and 237 for grain yield, 100-seed weight, heads/plant, and seeds/head, respectively. When the range of individual

Table 58. Mean within-plot standard deviations and ranges of individual means for grain yield and yield components, measured in 1969 and 1970 and combined over both years

Year and population type	Parameter	Standard deviations			
		Grain yield (g/plot)	100-seed weight (g)	Heads/plant	Seeds/head
1969					
A-lines	Mean	33.9	0.250	0.76	523
	Range	27.1 - 41.4	0.175 - 0.325	0.63 - 0.94	414 - 718
Sterile single-crosses	Mean	37.2	0.251	0.78	483
	Range	28.3 - 56.4	0.145 - 0.350	0.65 - 0.93	389-673
1970					
A-lines	Mean	29.2	0.247	0.69	497
	Range	25.2 - 33.4	0.195 - 0.335	0.59 - 0.79	419 - 593
Sterile single-crosses	Mean	35.9	0.306	0.63	586
	Range	25.3 - 48.3	0.205 - 0.410	0.40 - 0.94	469 - 699
1969 and 1970					
A-lines	Mean	31.6	0.249	0.73	510
	Range	27.8 - 33.3	0.185 - 0.290	0.61 - 0.86	416 - 656
Sterile single-crosses	Mean	36.6	0.279	0.71	535
	Range	30.3 - 44.0	0.232 - 0.360	0.57 - 0.87	436 - 627

means within both groups were compared in the light of these least significant differences it was found that the ranges observed in A-lines and in sterile single-crosses were very similar for each of the yield-related characters.

Table 59 shows the mean within-plot standard deviations for plant height and days to midbloom in sterile single-crosses. The analyses of variance of these standard deviations, combined over both years, are presented in Table 60. The analyses show that there were no significant differences among these hybrids for variability in plant height. Analysis of the within-plot variability for days to midbloom indicated that the major source of variation was among reciprocal crosses. Reciprocal crosses involving Martin as a parent consistently showed large differences for variability in days to midbloom (Table 59), ranging from a difference of 112% in crosses with Kafir 60 to 45% in crosses with Redlan. In all of the hybrids involving Martin, the hybrids having Martin as a female parent were more variable for days to midbloom than hybrids having Martin as a male parent. In contrast, there were no significant differences among A-lines *per se* for variability in days to midbloom (Table 60).

Sterile hybrids vs fertile hybrids

Statistically significant differences between the mean within-plot standard deviation of sterile single-crosses and that of fertile single-crosses plus three-way crosses were

Table 59. Mean within-plot standard deviations for plant height and days to midbloom in sterile single-crosses, measured in 1969 and 1970 and combined over both years

Hybrid	Standard deviations					
	Plant height			Days to midbloom		
	1969	1970	1969 & 1970	1969	1970	1969 & 1970
A Kafir 60 x B Martin	8.9	6.0	7.4	1.8	1.4	1.6
A Martin x B Kafir 60	7.0	11.7	9.3	2.9	3.9	3.4
A Kafir 60 x B Wheatland	5.4	4.6	5.0	1.4	1.2	1.3
A Wheatland x B Kafir 60	4.6	6.2	5.4	1.3	2.9	2.1
A Kafir 60 x B Redlan	6.3	6.1	6.2	1.3	3.0	2.1
A Redlan x B Kafir 60	7.2	7.2	7.2	1.2	3.4	2.3
A Martin x B Wheatland	8.9	7.9	8.4	2.5	2.6	2.6
A Wheatland x B Martin	6.5	4.3	3.4	1.4	1.4	1.4
A Martin x B Redlan	10.8	7.9	9.4	3.6	2.1	2.9
A Redlan x B Martin	7.8	5.7	6.8	1.5	2.7	2.0
A Wheatland x B Redlan	6.7	6.8	6.8	2.5	2.5	2.5
A Redlan x B Wheatland	8.3	3.1	5.7	1.6	1.9	1.8

Table 60. Analyses of variance of within-plot standard deviations for plant height and days to midbloom in sterile single-crosses and in sterile lines from combined 1969 and 1970 experiments

Source of variation	Degrees of freedom	Mean squares	
		Plant height	Days to midbloom
Among A-lines	3	32.69**	0.436
A-lines x years	3	5.73	0.487
Among sterile single-crosses	11	8.99	1.519**
Reciprocals	6	7.23	2.262**
g.c.a.	3	16.98	0.862
s.c.a.	2	2.25	0.276
Sterile single-crosses x years	11	6.33	1.177**
Reciprocals x years	6	7.92	0.982*
g.c.a. x years	3	7.31	1.652*
s.c.a. x years	2	0.11	0.735
Pooled error	174	7.74	0.44

indicated in the combined analyses for each character, with the exception of days to midbloom (Tables 46 and 54). Table 61 presents the mean levels of variability for each character in fertile and sterile hybrids in individual years, and for the data combined over years. In those cases where the combined analyses had indicated significant differences, it was the sterile single-crosses that exhibited the greater plant-to-plant uniformity. The relationship between the variability within these two groups of hybrids was consistent over years for grain yield and the yield components but not for plant

Table 61. Mean within-plot standard deviations in sterile and fertile hybrids, measured in 1969 and 1970 and combined over both years

Year and hybrid-type	Standard deviations					
	Plant height	Days to midbloom	Grain yield	100-seed weight	Heads/ plant	Seeds/ head
1969						
Sterile single-crosses	7.4	2.0	37.2	0.251	0.78	483
Fertile singles plus three-ways	10.2	2.6	45.2	0.333	0.83	567
1970						
Sterile single-crosses	6.5	2.4	35.9	0.306	0.63	586
Fertile singles plus three-ways	7.4	2.2	40.0	0.305	0.74	657
1969 and 1970						
Sterile single-crosses	7.2	2.2	36.6	0.279	0.71	535
Fertile singles plus Three-ways	8.8	2.4	42.6	0.323	0.78	612

height and days to midbloom (Tables 46 and 54). For the latter two characters the two groups differed by a significant amount for variability in 1969 (Appendix Table 70), but in 1970 statistical equivalence was indicated by the analyses (Appendix Table 71).

Hybrids vs parents

Within-plot variabilities for the parents and hybrids were for most characters statistically equivalent (Tables 46 and 54). In fact, significant differences were found only for variability in grain yield and plant height in the combined analyses. Mean within-plot standard deviations for each character in the parents and hybrids are presented in Table 62. Generally, the within-plot standard deviations for the parents were lower than those observed for the hybrids, and significantly so in the case of variability in grain yield and plant height. This relationship was consistent over years, as indicated by the data in Table 62 and the mean squares presented in Tables 46 and 54.

Comparisons among parents

The possibility that plant-to-plant variation might differ for lines that have different types of cytoplasm was investigated by comparing the variability observed in A-lines with that of their corresponding B-lines. Mean within-plot standard deviations for plant height and days to midbloom of the A and B-lines are presented in Table 63 for the years individually

Table 62. Mean within-plot standard deviations in parents and hybrids, measured in 1969 and 1970 and combined over both years

Year and population type	Standard deviations					
	Plant height	Days to midbloom	Grain yield	100-seed weight	Heads/ plant	Seeds/ head
1969						
Parents	8.0	2.3	39.9	0.31	0.81	555
Hybrids	9.8	2.5	44.0	0.32	0.82	553
1970						
Parents	6.5	2.2	31.5	0.27	0.69	559
Hybrids	7.2	2.2	39.3	0.30	0.71	646
1969 and 1970						
Parents	7.2	2.3	35.7	0.29	0.75	557
Hybrids	8.5	2.3	41.6	0.31	0.76	600

and combined. Similar means for yield-related characters are given in Table 64. Table 65 shows the mean squares for comparisons between parental types from the combined analysis for each character. Differences between the A-lines and B-lines for within-plot variability were not significant for any of the characters studied, and there were no indications of significant interactions with years. The differences among individual lines within any parental group were not significant (Table 63) with the exception of differences among

Table 63. Mean within-plot standard deviations for plant height and days to midbloom in parental lines, measured in 1969 and 1970 and combined over both years

Parental line	Standard deviations					
	Plant height			Days to midbloom		
	1969	1970	1969 & 1970	1969	1970	1969 & 1970
A Kafir 60	12.8	7.5	10.1	3.10	2.25	2.67
A Martin	5.8	5.2	5.5	1.50	2.25	1.87
A Wheatland	4.3	3.7	4.0	2.10	2.55	2.32
A Redlan	9.0	8.6	8.8	2.25	2.50	2.37
All A-lines	7.96	6.25	7.11	2.24	2.39	2.31
B Kafir 60	9.8	5.4	7.6	3.00	2.20	2.60
B Martin	5.8	6.7	6.2	1.95	1.60	1.77
B Wheatland	4.9	4.0	4.5	2.85	1.70	2.27
B Redlan	9.3	9.7	9.5	2.70	2.60	2.65
All B-lines	7.45	6.46	6.96	2.62	2.02	2.33
R Tx 7078	10.0	4.5	7.2	2.30	2.15	2.22
R Redbine 60	10.1	5.9	8.0	1.35	1.95	1.65
R Plainsman	5.9	9.4	7.7	2.30	2.65	2.47
R Caprock	8.3	6.8	7.5	2.70	2.05	2.37
All R-lines	8.59	6.67	7.6	2.16	2.20	2.18

A-lines for variability in plant height. A Martin and A Wheatland were the least variable for plant height and A Kafir 60 was the most variable (Table 63). The low level of variability observed in both A and B Martin for plant height and days to midbloom suggests that the variability in A Martin *per se*, resulting from either contamination or cytoplasmic

Table 64. Mean within-plot standard deviations for grain yield, 100-seed weight, heads/plant, and seeds/head in parental lines, measured in 1969 and 1970 and combined over both years

Parental line	Standard deviation					
	Grain yield			100-seed weight		
	1969	1970	1969 & 1970	1969	1970	1969 & 1970
A Kafir 60	27.1	28.4	27.8	0.17	0.19	0.18
A Martin	30.6	33.4	32.0	0.19	0.33	0.26
A Wheatland	36.1	29.9	33.0	0.31	0.20	0.26
A Redlan	41.4	25.2	33.3	0.32	0.25	0.29
All A-lines	33.8	29.2	31.6	0.25	0.25	0.25
B Kafir 60	47.4	34.8	41.1	0.34	0.18	0.26
B Martin	29.8	27.5	28.7	0.34	0.15	0.25
B Wheatland	53.4	35.3	44.4	0.28	0.25	0.26
B Redlan	42.7	36.3	39.5	0.31	0.43	0.37
All B-lines	43.3	33.5	38.4	0.32	0.25	0.29
R Tx 7078	42.4	29.1	35.8	0.28	0.32	0.30
R Redbine 60	40.8	31.6	36.2	0.30	0.25	0.28
R Plainsman	35.7	29.4	32.5	0.36	0.33	0.35
R Caprock	50.3	36.3	43.3	0.45	0.35	0.40
All R-lines	42.3	31.6	37.0	0.35	0.31	0.33

Standard deviation					
Heads/plant			Seeds/head		
1969	1970	1969 & 1970	1969	1970	1969 & 1970
0.74	0.71	0.72	506	429	467
0.72	0.69	0.71	456	546	501
0.94	0.79	0.86	414	419	416
0.63	0.59	0.61	718	594	656
0.76	0.70	0.73	523	497	510
0.76	0.74	0.75	779	747	763
0.85	0.51	0.68	533	480	506
0.96	0.79	0.87	411	625	518
0.68	0.61	0.65	705	504	604
0.82	0.66	0.74	607	589	598
1.13	0.77	0.95	498	397	448
0.81	0.76	0.79	421	550	485
0.70	0.66	0.68	511	637	604
0.82	0.68	0.75	655	782	718
0.87	0.72	0.79	536	591	564

Table 65. Mean squares for comparison within and between parental types for within-plot standard deviations, from combined analyses

Source of variation	Degrees of freedom	Mean squares					
		Plant height	Days to midbloom	Grain yield	100-seed weight	Heads/ plant	Seeds/ head
Among A-lines	3	32.69**	0.436	26.3	0.008	0.044	42588
A-lines x years	3	5.73	0.487	75.7	0.012	0.003	8900
Among B-lines	3	18.02	0.648	185.7	0.014	0.040	56048
B-lines x years	3	5.82	0.218	48.5	0.020	0.020	29663
Among R-lines	3	0.44	0.544	82.5	0.012	0.053	60092
R-lines x years	3	16.04	0.307	13.0	0.003	0.022	11678
A-lines vs B-lines	1	0.18	0.000	380.9	0.010	0.001	61952
(A-lines vs B-lines x years	1	1.04	1.125	54.1	0.010	0.016	128
(A + B) lines vs R-lines	1	3.84	0.202	42.7	0.042	0.038	963
(A + B) lines vs R-lines x years	1	0.87	0.187	32.7	0.000	0.003	15811
Entries x years	87	8.94	0.50	109.0	0.014	0.038	17296
Pooled error	174	7.74	0.44	109.9	0.009	0.029	28614

effects, was not the cause of the reciprocal differences noted in sterile single-crosses involving Martin as a parent (Table 59).

The variability of R-lines, as a group, was not significantly different from that of A-lines plus B-lines, as a group, for any of the characters studied (Table 65). However, the R-lines were generally slightly more variable than the A and B-lines for all characters except days to midbloom (Tables 63 and 64). This result was somewhat surprising, especially for yield-related characters, since it might be expected that male-sterile lines, dependent on cross pollination, would show relatively higher levels of variability for characters such as seeds/head and 100-seed weight than would the self-fertile lines. It may be that a positive relationship between the magnitude of plot means and within-plot standard deviations was instrumental in equalizing levels of variability in R-lines and A and B-lines.

DISCUSSION

One of the main objectives of this study was to compare grain yields of single-crosses and three-way hybrids of grain sorghum under Iowa conditions. Although the parental lines used could not be considered a set selected at random from the germplasm available to sorghum breeders, thereby allowing inferences to be made to grain sorghum in general, they may be considered representative of the germplasm currently available in Iowa for use in the development of superior hybrids. Accordingly, inferences may be made only to that pool of germplasm.

Mean grain yields of single-crosses and three-way hybrids were statistically equivalent in each of the years in which the study was conducted (Appendix Tables 66 and 67), and when the data from both years were combined (Table 6). In fact, one of the most striking features of the yield data was the very close similarity between the means of these hybrid types (Table 7). Expressed as a percentage of the single-cross mean, the difference between the two groups was only 1% in each of the two years. Furthermore, the ranges among individual hybrid means within each group were quite similar (Table 7), although the highest yielding three-way hybrid always outyielded the highest yielding single-cross.

These results are in close agreement with those reported previously for grain sorghum (Stephens and Lahr, 1959; Doggett

and Majisu, 1966; Liang, 1971). Also, they are in agreement with results published by Ross (1969) in that when years were combined, a significant difference in grain yield between single-crosses and three-way hybrids was not found. In the study reported by Ross (1969) differences in grain yield between single-crosses and three-way hybrids were statistically significant in some years but not in others. The fact that significant differences were not found in individual years in this study may be explained by the fact that testing was conducted over only two years, both of which were quite similar in terms of suitability for the growth and development of grain sorghum.

Under conditions of uniform stand levels, the three characters, grain weight, seeds/head, and heads/plant, are the components of yield, and, when measured accurately give a precise account of the manner in which the yield of a genotype is made up. It must be remembered, however, that these yield components are not the determinants of yield. Grain yield depends ultimately on environmental factors such as available moisture, soil fertility, and temperature together with the physiological efficiency of the plant in utilizing these factors in the production of grain. The lack of a significant difference between the single-cross and three-way hybrids for any of the yield components (Table 6) indicates that both hybrid types exploited these factors in similar ways.

The single- and three-way crosses were very similar for

days to midbloom and plant height. Two-year means differed by only 0.2 days for days to midbloom, and by only 0.9 cm for plant height (Table 31). Neither of these differences was significant statistically (Table 32). In the individual year analyses for these traits the only instance in which single- and three-way crosses differed significantly was for plant height in 1970 (Appendix Table 69). Even in this instance it is doubtful if the 2.2 cm greater height of the single-crosses (Table 31) is of practical importance. Similar results have been reported by Ross (1969). As in the case of grain yield, the ranges among individual hybrid means for days to midbloom and plant height were similar in both groups of hybrids (Table 31).

Since single-crosses and three-way hybrids were equivalent in grain yield, days to midbloom, and plant height there would appear to be no great incentive to change from single-crosses to three-way crosses unless three-way hybrids can be shown to have advantages for growers or seed producers in traits other than yield, maturity or height. Characteristics for which three-way hybrids might have an advantage for the grower include greater stability of performance in varying environments, and for the seed producer there might be an advantage in a lower production cost per bushel of seed. Advantages which might be demonstrated under these headings would have to be balanced against any disadvantages which three-way hybrids might have.

There was some indication in my experiments that three-way hybrids had greater stability for grain yield than did the single-crosses (Tables 10 and 11). However, this study was not designed to evaluate relative stabilities of the populations so it is only an indication which may be supported or refuted by subsequent experiments conducted over several locations and years. Similar indications of greater stability in three-way sorghum hybrids have been reported by at least two other workers (Doggett and Majisu, 1966; Ross, 1969).

Whether the production of three-way cross seed would be attractive to seed producers, or not, would depend, to a large extent, on the seed-producing ability of sterile single-crosses. The land area required for the production of three-way hybrid seed would be greater than that needed to produce seed of single-crosses. Furthermore, the seed producer would incur extra storage and handling expenses in producing seed of three-way crosses. To offset these increased costs, which would eventually be passed on to the grower, it would be necessary for sterile single-cross parents to be superior to sterile lines in seed yield and in other agronomic characters.

In my experiments the sterile single-crosses were superior to sterile lines as seed parents, with the former yielding 19% more than the latter (Table 19) over the two-year period. This difference was highly significant (Table 20). In individual years, the superiority of single-cross seed parents ranged from 14% in 1969 to 24% in 1970 (Table 19), but only

in 1970 was the difference significant (Table 20). The higher yields of sterile single-crosses relative to the A-lines resulted largely from greater numbers of seeds/head. This advantage more than compensated for the larger seed-size of the A-lines, although differences between two-year means for the two groups were not significant for any of the yield components (Table 20). Similar findings have been reported by Stephens and Lahr (1959). The differences between A-lines and sterile single-crosses for days to midbloom and plant height (Table 40) were very small when two-year means were compared and would not appear to be of sufficient magnitude to offset the advantage in seed yield shown by the sterile single-crosses.

There are also some possible disadvantages for three-way hybrids in comparison with single-crosses. One possible disadvantage would be the level of within-hybrid variability, because in the production of three-way hybrids there is an opportunity for segregation and recombination which does not exist in the production of single-crosses. Research with naturally self-pollinating species has indicated that controlled levels of heterogeneity may be advantageous (Allard, 1961; Gustafsson, 1946), but it has also been shown that there is an upper limit, set by the needs of growers and processors, to the variability acceptable within populations if they are to be useful. Stephens and Lahr (1959) have suggested that three-way grain sorghum hybrids are not necessarily more

variable for important agronomic characters than single-crosses, but data to support or refute this contention have not been published.

In reflecting on my investigations I have not defined an upper limit for variability for any character, but have taken the level of variability within single-crosses as an acceptable level and evaluated three-way hybrids in relation to this standard. Also, in this context one has to distinguish between deviations that are significant statistically and deviations from the standard that may have biological significance. One also has to decide for which characters variability is of consequence to the grower or processor.

It seems that, of the characters studied, plant height and days to midbloom are the ones in which variability would be most important. Variability in grain yield per plant would seem to be of little consequence since a grower is concerned with yield per unit area. Among the yield components, it is conceivable that gross variability in seed size, as measured by 100-seed weight, could cause problems in adjusting the combine for efficient threshing of the grain. Variability in seeds/head would appear not to be of importance. Variability for heads/plant would also seem to have little practical importance, except that it may effect the variability for days to midbloom when both the main stalk and tiller heads are considered.

For plant height and days to midbloom the three-way

hybrids were more variable than single-crosses in the individual years and in the data combined over both years (Table 47). Although these differences were significant statistically (Appendix Tables 70 and 71, Table 46), it is doubtful that they are of sufficient magnitude to be important biologically. The mean within-plot standard deviations for plant height of the two groups differed by only 1.8 cm for the combined year data. The insignificance of this difference from a field-scale production standpoint may be illustrated by comparing the distribution of individual plant heights within single-crosses with that in three-way hybrids. Mean within-plot standard deviations for plant height in single-crosses and three-way crosses were 7.4 and 9.2 cm, respectively (Table 47). Assuming a normal distribution of plant heights within each population and that 95% of the individuals in either population will be included in the range $X \pm 2SD$, these data show that in a single-cross the plants will differ in height within a range of approximately 30 cm, while in a three-way cross the range will be approximately 37 cm, a difference of 7 cm (about 3 inches). In setting the cutter bar for harvesting it is doubtful if a combine operator would be working with such precision that a difference of this magnitude would create a serious problem.

If the same assumptions and reasoning are applied to the results for days to midbloom (Table 47), it is found that virtually all plants within a single-cross would reach midbloom

within approximately 8 days of each other, and that the range in three-way hybrids would be 10 days. It does not seem that a difference of this magnitude would be of practical importance. However, my notes for days to midbloom were taken only on the main stalk head, and if the period of tiller production was not of equal duration in both types of hybrids these results could be misleading, since early or late formed tillers should prolong the period during which individual heads within a population would reach midbloom. Estimates of differences in variability for days to midbloom in two populations, based on observations on the main stalk heads, would also be expected to be biased if the number of heads/plant, or the variability for heads/plant, were substantially different in the two populations. My results showed, however, that the number of heads/plant was virtually the same in both types of hybrids (Tables 6 and 7), and that the variability for heads/plant was significantly greater in single-crosses than in three-way crosses (Tables 54 and 55). Therefore, any bias in the estimates of variability for midbloom would be of the type that would lead to an underestimation of the variability in single-crosses.

In adjusting threshing equipment, seed size must be taken into account if excessive damage to the seed is to be avoided. Therefore, hybrids with high levels of variability for seed size are undesirable. In this study three-way hybrids, as a

group, were no more variable for this character than single-crosses as a group (Tables 54 and 55). It was observed, however, that the range of within-plot standard deviations among individual three-way hybrids was somewhat wider than the range among the single-crosses (Table 55). A comparison of the most variable hybrids within each group showed that the range of 100-seed weights in the single-cross was 1.56 g in contrast to 1.96 g in the three-way cross, a difference which does not appear to be sufficient to cause concern.

Although the differences between single-crosses and three-way crosses for variability in plant height and days to midbloom are considered too small to be of practical importance, it is of interest to inquire into the reasons why three-way hybrids were more variable for these characters than single-crosses. What were considered the most likely causes, namely, differences between parents of the sterile single-cross and heterogeneity within parental lines (resulting from mutation, outcrossing, or mechanical contamination) were investigated. But when differences between parents of the sterile single-cross were correlated with levels of variability in three-way hybrids involving that sterile single-cross, the correlation coefficients for plant height were not significantly different from zero in either of the individual years, nor when data from both years were combined (Table 50). Similar correlations for days to midbloom gave a coefficient that was significantly greater than zero in only one of the

years. These results are in accord with those of Pinnell (1943) who concluded that it was not possible to predict the relative variability of double-cross maize hybrids on the basis of character means of the inbreds, because unrelated inbreds that look alike for a particular character very probably differ for some of the genes controlling that character. It would seem that unless very diverse parents were being used, the suggestion of Rosenow (1968) that great care should be exercised in selecting parents for sterile single-crosses in the production of three-way grain sorghum hybrids, so that the resulting three-way hybrid would not be excessively variable, is unwarranted.

The influence of heterogeneity within parental lines on within-hybrid variability was evaluated by comparing within-plot standard deviations of parental lines per se and those of the same lines in hybrid combination (Table 51). In general there was little indication of an association between the variability within parental lines and the variability of the single-cross or three-way hybrid involving those lines. This result would be expected if the variability observed in parents was due to environmental causes rather than genetic heterogeneity.

It is generally recognized that excessive variability within a crop population is not desirable, especially where field operations are highly mechanized. The results presented have shown that three-way hybrids evaluated in this study were

not excessively variable. It has also been suggested that limited genetic diversity within a crop population may be advantageous from the point of view of both production and stability (Allard, 1961; Reich and Atkins, 1970). The results from my experiments, however, do not provide strong support for this contention. Correlation coefficients describing the relationship between grain yield and variability for yield components were either not significantly different from zero or they were significant and negative (Table 49). Yielding ability was not related to variability in plant height. Variability in days to midbloom was significantly and positively related to grain yield in three-way hybrids, but it was significantly and negatively related to grain yield in the single-crosses.

If three-way crosses, in the light of stability studies etc., do prove desirable, information will be needed on procedures for getting the best combination of lines together into a three-way hybrid. In this context, methods of predicting the performance of three-way crosses will become important. The usefulness of these methods, and the particular method to be used, will be influenced by the relative importance of nonadditive gene action in the inheritance of traits for which predictions are desired. In my study two methods of predicting grain yield in three-way hybrids were evaluated. One method, analogous to Jenkins Method B (Jenkins, 1934), was one in which both additive and dominance types of gene

action were taken into account. The other method, based on parental performance per se, takes only additive gene action into account. Three-way cross yields were predicted from two-year means for single-crosses and parental lines and then compared with the observed two-year means for the three-way hybrids (Table 29).

Yields predicted on the basis of performance of parental lines per se were rather poorly correlated with the observed yields ($r = 0.45$). This indicated that some form of nonadditive gene action, either dominance or epistasis, was involved in the inheritance of grain yield in this material. When yields predicted on the basis of the performance of nonparental single-crosses (Jenkins Method B) were correlated with observed yields a considerably higher correlation coefficient was obtained ($r = 0.70$). The efficiency with which Jenkins Method B predicted yields of three-way hybrids is illustrated in Table 30. This result, along with the fact that three-way hybrids and single-crosses did not differ significantly in grain yield (Table 6), implies that epistasis was of little consequence, an implication which agrees with the findings of Ross (1969) and Liang (1971).

If the contribution of epistasis is negligible then dominance effects must explain the poor predictions from parental line performance data and the fact that considerable heterosis was expressed for grain yield (Tables 6 and 24). However, this contention leaves unexplained the fact that

the mean squares for specific combining ability in the analyses of yield data in fertile single-crosses and in three-way crosses were not significant in either of the individual years (Appendix Tables 66 and 67) or in the data combined over years (Tables 10 and 11). However, a situation can be visualized in which significant heterosis could be observed although specific combining ability mean squares were nonsignificant. Consider a series of loci showing dominance, and all of nearly equal effect. If in each of the parental lines two different loci carry dominant alleles, then the same level of heterosis will be expressed regardless of the parental combination. Since all hybrids show the same level of heterosis, relative to the mid-parent, specific combining ability mean squares would not be significant.

SUMMARY

Replicated experiments were conducted at Ames, Iowa during 1969 and 1970 to evaluate the performance and within-plot variability of single-cross and three-way hybrids of grain sorghum. Four A-lines, their corresponding B-lines, and four R-lines were used to produce 12 male-sterile single-crosses (A x B), 16 male-fertile single-crosses (A x R), and 48 three-way crosses [(A x B) x R]. These 76 hybrids and the 12 parental lines were entries in two separate experiments in each year. In one experiment data were recorded for each plot for grain yield. In the other experiment data were recorded for 10 competitive plants within each plot for plant height, days to midbloom, and the primary components of grain yield; heads/plant, seeds/head, and 100-seed weight.

Although the highest yielding three-way hybrid always outyielded the highest yielding single-cross, mean grain yields of single-crosses and three-way hybrids were statistically equivalent in each year and when data from both years were combined. Expressed as a percentage of the single-cross mean, the difference between the two groups was only one percent in in each of the two years. Comparison of hybrid-type x year mean squares for grain yield indicated that three-way hybrids might have greater stability of performance than single-crosses. However, these experiments were not conducted over a range of environments sufficiently wide to allow an accurate

evaluation of yield stability. Yield structure was the same in both hybrid types as evidenced by the lack of significant differences between group means for any of the yield components.

The single- and three-way crosses were very similar for days to midbloom and plant height. Two-year means differed by only 0.2 days for days to midbloom, and by only 0.9 cm for plant height. Neither of these differences were significant statistically. Furthermore, the ranges among individual hybrid means for these traits were similar in both groups of hybrids.

Sterile single-crosses were superior to sterile lines as seed parents, with the former yielding 19% more than the latter over the two-year period. In individual years this superiority ranged from 14% in 1969 to 24% in 1970. The higher seed yields of sterile single-crosses relative to the A-lines resulted largely from greater numbers of seeds/head which more than compensated for the larger seed-size of the A-lines. Differences between the two types of seed parents for days to midbloom and plant height were very small and would not appear to be of sufficient magnitude to offset the advantage in seed yield shown by the sterile single-crosses.

Mean within-plot standard deviations for plant height and days to midbloom were significantly larger for three-way hybrids than single-crosses, in each of the individual years and when data were combined from both years. However, assuming a normal distribution of plant heights and days to midbloom

within each population and that 95% of the individuals within each population would be included in the range $X \pm 2SD$, the variability within single-crosses and three-way hybrids for these two characters was very similar, and the differences observed would be unlikely to be of practical importance. Variability in seed size was essentially the same for both hybrid types.

Causes for the greater variability for days to midbloom and plant height in three-way hybrids were not established. Neither differences between parents of sterile single-crosses nor variability within parental lines per se, appeared to be closely associated with variability within three-way hybrids.

The contention that limited genetic diversity within a population may be advantageous from the point of view of production was not supported by the results of these experiments. Correlation coefficients describing the relationship between grain yield and variability for yield components were either not significantly different from zero or they were significant and negative. Yielding ability was not related to variability in plant height. Variability in days to midbloom was significantly and positively related to grain yield in three-way hybrids, but it was significantly and negatively related to grain yield in the single-crosses.

Two methods of predicting grain yields in three-way hybrids were evaluated. One method, based on the performance of parental lines per se, which took only additive gene action

into account, predicted yields that were rather poorly correlated with observed yields of three-way hybrids. The other method, analogous to Jenkins Method B, which took additive and dominance types of gene action into account, gave predicted yields which were highly correlated with observed yields. The relative efficiencies of the two prediction methods, in addition to the observed heterosis, suggested that both additive and dominance types of gene action were both important in the inheritance of grain yield in this material. The equivalence of yields of three-way hybrids and related single-crosses suggested that epistasis was of little importance.

LITERATURE CITED

Allard, R. W. 1961. Relationship between genetic diversity and consistency of performance. Crop Science 1: 127-133.

Beil, G. M. and Atkins, R. E. 1967. Estimates of general and specific combining ability in F_1 hybrids for grain yield and its components in grain sorghum, Sorghum vulgare Pers. Crop Science 7: 225-228.

Burton, G. W. 1948. The performance of various mixtures of hybrid and parent inbred pearl millet, Pennisetum glaucum (l) R. Br. Journal of the American Society of Agronomy 40: 908-915.

Chinwuba, P. M., Grogan, C. O., and Zuber, M. S. 1961. Interaction of detasselling, sterility and spacing on yields of maize hybrids. Crop Science 1: 279-280.

Cochran, W. G. and Cox, G. M. 1957. Experimental designs. 2nd ed. New York, New York, John Wiley and Sons, Inc.

Cockerham, C. C. 1961. Implications of genetic variances in a hybrid breeding program. Crop Science 1: 47-52.

Comstock, R. E. and Robinson, H. F. 1952. Estimation of average dominance of genes. Pp. 494-516. In J. W. Gowen (ed). Heterosis. Ames, Iowa, Iowa State University Press.

Doggett, H. and Majisu, B. W. 1966. Sorghum in Uganda. Sorshum Newsletter 9: 85.

Duvick, D. N. 1958. Yields and other agronomic characteristics of cytoplasmically pollen sterile corn hybrids, compared to their normal counterparts. Agronomy Journal 50: 121-125.

Duvick, D. N. 1965. Cytoplasmic pollen sterility in corn. Advances in Genetics 13: 1-56.

Eberhart, S. A. and Hallauer, A. R. 1968. Genetic effects for yield in single, three-way and double cross maize hybrids. Crop Science 8: 377-379.

Eberhart, S. A. and Russell, W. A. 1969. Yield and stability for a 10-line diallel of single-cross and double-cross maize hybrids. Crop Science 9: 357-361.

Eberhart, S. A., Russell, W. A., and Penny, L. H. 1964. Double cross hybrid prediction in maize when epistasis is present. Crop Science 4: 363-366.

Eckhart, R. C. and Bryan, A. A. 1940. Effect of the method of combining two early and two late inbred lines of corn upon the yield and variability of the resulting double crosses. Journal of the American Society of Agronomy 32: 645-656.

Fleming, A. A., Kozelnicky, G. M., and Browne, E. B. 1960. Cytoplasmic effects on agronomic characters in a double cross maize hybrid. Agronomy Journal 52: 112-115.

Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel crossing systems. Australian Journal of Biological Science 9: 463-493.

Griffing, B. and Langridge, J. 1963. Phenotypic stability of growth in the self-fertilized species Arabidopsis thaliana. Statistical Genetics in Plant Breeding. Nat. Acad. Sci. NRS 982: 368-390.

Grogan, C. O., Sarvalla, P., Sanford, J. O., and Jordan, H. V. 1965. Influence of cytoplasmic male sterility on dry matter accumulation in maize (Zea mays L.). Crop Science 5: 365-367.

Gustafsson, A. 1946. The effect of heterozygosity on variability and vigor. Hereditas 32: 263-285.

Hadley, H. H. 1957. An analysis of variation in height in sorghum. Agronomy Journal 49: 144-147.

Jenkins, N. T. 1934. Methods of estimating the performances of double crosses in corn. Journal of the American Society of Agronomy 26: 199-204.

Jinks, J. M. and Mather, K. 1955. Stability in development of heterozygotes and homozygotes. Proceedings of the Royal Society 143: 561-578.

Jones, D. F. 1950. The interrelation of plasmagenes and chromogenes in pollen production in maize. Genetics 35: 507-512.

Jones, D. F. 1956. Genic and cytoplasmic control of pollen abortion in maize. Brookhaven Symposia in Biology No. 9 (Genetics in Plant Breeding): 101-112.

Kambal, A. E. and Webster, O. J. 1965. Estimates of general and specific combining ability in grain sorghum, Sorghum vulgare, Pers. Crop Science 5: 521-523.

Kern, J. 1969. Cytoplasm effects in relation to male sterility and agronomic performance of grain sorghum, Sorghum bicolor (L) Moench. Unpublished Ph.D. dissertation. Ames, Iowa, Library, Iowa State University.

King, J. G., Quinby, J. R., Stephens, J. C., Kramer, N. W., and Lahr, K. A. 1961. An evaluation of parents of grain sorghum hybrids. Texas Agricultural Experiment Station Misc. Publ. 510.

Kohel, R. J. 1969. Phenotypic stability of homozygous parents and their F_1 hybrids in Upland cotton, Gossypium hirsutum L. Crop Science 9: 85-87.

Kohel, R. J. and White, T. G. 1963. An analysis of the variability of five parents and their F_1 progenies in Gossypium hirsutum L. Crop Science 3: 359-361.

LeClerg, E. L., Leonard, W. H., and Clark, A. G. 1962. Field plot technique. 2nd ed. Minneapolis, Minnesota, Burgess Publishing Company.

Lerner, I. M. 1954. Genetic homeostasis. New York, New York, John Wiley and Sons, Inc.

Liang, G. H. 1971. Epistasis in grain sorghum. Sorghum Newsletter 14: 85.

Liang, G. H. and Walter, T. L. 1968. Heritability estimates and gene effects for agronomic traits in grain sorghum, Sorghum vulgare Pers. Crop Science 8: 77-81.

Niehaus, M. H. and Pickett, R. C. 1966. Heterosis and combining ability in a diallel cross in Sorghum vulgare Pers. Crop Science 6: 33-36.

Paxman, G. J. 1956. Differentiation and stability in the development of Nicotiana rustica. Annals of Botany (N.S.) 20: 331-347.

Pinnell, E. L. 1943. The variability of certain quantitative characters of a double-cross hybrid in corn as related to the method of combining the four inbreds. Journal of the American Society of Agronomy 35: 508-514.

Quinby, J. R. 1970. Effects of male-sterile-inducing cytoplasm in sorghum hybrids. Crop Science 10: 614.

Reich, V. H. and Atkins, R. E. 1970. Yield stability of four population types of grain sorghum, Sorghum bicolor (L.) Moench, in different environments. Crop Science 10: 511-517.

Robertson, F. W. and Reeve, E.C.R. 1952. Heterozygosity, environmental variation and heterosis. Nature 170: 286.

Rogers, J. S. and Edwardson, J. R. 1952. The utilization of cytoplasmic male-sterile inbreds in the production of corn hybrids. Agronomy Journal 44: 8-13.

Rojas, B. A. and Sprague, G. F. 1952. A comparison of variance components in corn yield trials: III. General and specific combining ability and their interaction with location and years. Agronomy Journal 44: 462-466.

Rosenow, D. T. 1968. Seed production with 4-dwarf seed rows. Sorghum Newsletter 11: 97.

Ross, W. M. 1961. Hybrid mixtures. Sorghum Newsletter 4: 29.

Ross, W. M. 1965. Yields of Sorghum vulgare Pers. populations with various degrees of male sterility. Crop Science 5: 480.

Ross, W. M. 1969. Performance of three-way sorghum hybrids. Corn and Sorghum Research Conference Annual Proceedings 24: 129-134.

Shaalan, M. I., Heyne, E. G., and Lofgren, J. R. 1966. Mixtures of hard red winter wheat cultivars. Agronomy Journal 58: 89-91.

Smith, H. H. and Daly, K. 1959. Discrete populations derived by interspecific hybridization and selection in Nicotiana. Evolution 13: 476-487.

Snedecor, G. W. and Cochran, W. G. 1967. Statistical methods. 6th ed. Ames, Iowa, Iowa State University Press.

Sprague, G. F., Federer, W. T. 1951. A comparison of variance components in corn yield trials: II. Error, year x variety, location x variety, and variety components. Agronomy Journal 43: 535-541.

Sprague, G. F. and Tatum, L. A. 1942. General vs. specific combining ability in single crosses of corn. Journal of the American Society of Agronomy 34: 923-932.

Sprague, G. F. and Thomas, W. I. 1967. Further evidence of epistasis in single and three-way cross yields of maize (Zea mays L.). Crop Science 7: 355-356.

Sprague, G. F., Russell, W. A., Penny, L. H., Horner, T. W., and Hanson, W. T. 1962. Effect of epistasis on grain yield in maize. Crop Science 2: 205-208.

Stephens, J. C. and Holland, R. F. 1954. Cytoplasmic male sterility for hybrid sorghum seed production. Agronomy Journal 46: 20-23.

Stephens, J. C. and Lahr, K. A. 1959. Single cross vs. three-way sorghum hybrids. Agronomy Abstracts 1959: 67.

Stephens, J. C., Kuykendall, G. E., and George, D. W. 1952. Experimental production of hybrid sorghum seed with a three-way cross. Agronomy Journal 44: 369-373.

Stringfield, G. H. 1950. Heterozygosis and hybrid vigor in maize. Agronomy Journal 42: 145-152.

Weatherspoon, J. H. 1970. Comparative yields of single, three-way and double crosses of maize. Crop Science 10: 157-159.

Whitehead, W. L. 1962. The breeding behaviour of phenotypically diverse grain sorghum varieties in hybrid combination. Unpublished Ph.D. dissertation. Lafayette, Indiana, Library, Purdue University.

Williams, W. 1960. Relative variability of inbred lines and F_1 hybrids in Lycopersicum esculentum. Genetics 45: 1457-1465.

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APPENDIX

Table 66. Analyses of variance for grain yield and its components for 1969 experiment

Source of variation	Degrees of freedom	Mean squares			
		Grain yield	100-seed weight	Seeds/ head	Heads/ plant
Replicates	1	24511	0.01	373	0.44*
Entries	87	149609**	0.34**	253305**	0.14
Fertile singles vs three-ways	1	55224	0.00	34164	0.23
Hybrids vs parents	1	3740696**	0.48*	1071546**	0.62*
Sterile singles vs (fertile singles + three-ways)	1	345029**	13.82**	7815332**	0.23
Among parents	11	70352	0.48**	421989**	0.19*
Among A-lines	3	128101*	0.10	339577**	0.36*
Among B-lines	3	17822	0.14	15195	0.06
Among R-lines	3	88473	0.10	245223*	0.24
A vs B-lines	1	65664	1.77**	1281175**	0.12
(A+B-lines) vs R-lines	1	5023	2.52**	1560720**	0.00
Among sterile single-crosses	11	122178**	0.04	81246	0.06
Reciprocals	6	60889	0.01	42772	0.04
g.c.a.	3	172396**	0.11	176010*	0.04
s.c.a.	2	230724**	0.02	54522	0.16
Among fertile single-crosses	15	171992**	0.07	186695**	0.12
g.c.a. (males)	3	220662**	0.18	66488	0.14
g.c.a. (females)	3	441923**	0.06	328108**	0.16
s.c.a.	9	65793	0.04	179626**	0.09

Table 66. (Continued)

Source of variation	Degrees of freedom	Mean squares			
		Grain yield	100-seed weight	Seeds/ head	Heads/ plant
Among three-way crosses	47	88907**	0.06	100016*	0.13
R-lines	3	483278**	0.37**	134923	0.64**
Sterile single crosses	11	80564*	0.07	96033	0.06
Reciprocals	6	24991	0.04	54030	0.03
g.c.a.	3	203431**	0.17	185652*	0.16
s.c.a.	2	57984	0.03	87614	0.04
Sterile singles x R-lines	33	55837	0.03	98171	0.11
Reciprocals x R-lines	18	74691*	0.02	66489	0.08
g.c.a. x R-lines	9	44168	0.05	205707**	0.16
s.c.a. x R-lines	6	16775	0.02	31914	0.13
Error (reps x entries)	87	42057	0.08	64003	0.10
Total	175				

Table 67. Analyses of variance for grain yield and its components for 1970 experiment

Source of variation	Degrees of freedom	Mean squares			
		Grain yield	100-seed weight	Seeds/ head	Heads/ plant
Replicates	1	24795	0.019	197986	0.010
Entries	87	183164**	0.137**	207132**	0.099**
Fertile singles vs three-ways	1	53346	0.000	19794	0.235*
Hybrids vs parents	1	7378977**	0.579**	4001248**	0.000
Sterile singles vs (fertile singles + three-ways)	1	394272**	3.678**	1512455**	0.574**
Among parents	11	190687**	0.332**	490374**	0.120*
Among A-lines	3	170484*	0.107**	500656**	0.198*
Among B-lines	3	55590	0.022	277210*	0.062
Among R-lines	3	234641**	0.097**	305536**	0.162*
A vs B-lines	1	220900*	2.016**	1623076**	0.048
(A+B-lines) vs R-lines	1	494508**	0.963**	520833**	0.010
Among sterile single-crosses	11	46071	0.056**	74489	0.074
Reciprocals	6	43107	0.065**	76948	0.063
g.c.a.	3	43795	0.068**	75436	0.117
s.c.a.	2	58379	0.012	65696	0.041
Among fertile single-crosses	15	62169	0.058*	109721	0.092
g.c.a. (males)	3	82197	0.205**	256331*	0.105
g.c.a. (females)	3	32700	0.041	103286	0.125
s.c.a.	9	65317	0.008	62996	0.077

Table 67. (Continued)

Source of variation	Degrees of freedom	Mean squares			
		Grain yield	100-seed weight	Seeds/ head	Heads/ plant
Among three-way crosses	47	97267**	0.054**	98459	0.093*
R-lines	3	489412**	0.485**	267074*	0.049
Sterile single-crosses	11	109682*	0.042**	163052*	0.194**
Reciprocals	6	36861	0.028	171116*	0.210**
g.c.a.	3	289241**	0.023	203249*	0.176*
s.c.a.	2	58807	0.109**	78565	0.176*
Sterile singles x R-lines	33	57479	0.018	61600	0.063
Reciprocals x R-lines	18	54394	0.015	57907	0.054
g.c.a. x R-lines	9	82270	0.029	48929	0.089
s.c.a. x R-lines	6	29551	0.013	91685	0.052
Error (reps x entries)	87	53464	0.016	74418	0.053
Total	175				

Table 68. Analyses of variance for days to midbloom and plant height for 1969 experiment

Source of variation	Degrees of freedom	Mean squares: Days to midbloom	Mean squares: Plant height
Replicates	1	1.37	2.49
Entries	87	8.07**	272.45**
Fertile singles vs three-ways	1	0.94	3.57
Hybrids vs parents	1	85.47**	584.06**
Sterile singles vs (fertile singles + three-ways)	1	164.94**	14.84
Among parents	11	1.97	475.97**
Among A-lines	3	0.89	438.09**
Among B-lines	3	3.07	472.73**
Among R-lines	3	2.77	636.88**
A vs B-lines	1	1.44	3.72
(A+B-lines) vs R-lines	1	0.01	588.84**
Among sterile single-crosses	11	4.69	179.98**
Reciprocals	6	3.39	51.94*
g.c.a.	3	4.88	547.60**
s.c.a	2	8.31	12.32
Among fertile single-crosses	15	6.55*	353.81**
g.c.a. (males)	3	2.44	1043.76**
g.c.a. (females)	3	13.81*	497.72**
s.c.a.	9	5.50	75.86**
Among three-way crosses	47	5.66*	225.13**
R-lines	3	26.76**	2371.54**
Sterile single-crosses	11	2.41	200.62**
Reciprocals	6	2.45	85.66**
g.c.a.	3	3.72	515.52**
s.c.a.	2	0.32	73.34*
Sterile singles x R-lines	33	4.83	38.17**
Reciprocals x R-lines	18	3.74	38.32*
g.c.a. x R-lines	9	7.63*	27.70
s.c.a. x R-lines	6	3.88	52.56*
Error (reps x entries)	87	3.56	20.12
Total	175		

Table 69. Analyses of variance for days to midbloom and plant height for 1970 experiment

Source of variation	Degrees of freedom	Mean squares: Days to midbloom	Mean squares: Plant height
Replicates	1	7.17*	34.20
Entries	87	7.73**	116.39**
Fertile singles vs three-ways	1	0.19	114.84**
Hybrids vs parents	1	95.30**	452.50**
Sterile singles vs (fertile singles + three-ways)	1	72.82**	10.93
Among parents	11	18.42**	145.73**
Among A-lines	3	26.13**	80.44**
Among B-lines	3	28.55**	89.55**
Among R-lines	3	7.10**	297.10**
A vs B-lines	1	0.00	0.04
(A+B-lines) vs R-lines	1	17.28**	201.72**
Among sterile single-crosses	11	8.14**	57.46**
Reciprocals	6	3.44*	14.78
g.c.a.	3	22.66**	168.28**
s.c.a.	2	0.49	19.30
Among fertile single-crosses	15	3.69**	150.72**
g.c.a. (males)	3	0.57	526.30**
g.c.a. (females)	3	14.71**	146.42**
s.c.a.	9	1.06	26.96**
Among three-way crosses	47	3.34**	107.53**
R-lines	3	9.79**	1230.19**
Sterile single-crosses	11	7.47**	35.09**
Reciprocals	6	1.02	5.32
g.c.a.	3	22.76**	114.42**
s.c.a.	2	3.88*	5.43
Sterile singles x R-lines	33	1.38	29.61**
Reciprocals x R-lines	18	1.20	28.09**
g.c.a. x R-lines	9	1.71	44.90**
s.c.a. x R-lines	6	4.65**	11.26
Error (reps x entries)	87	1.23	10.03
Total	175		

Table 70. Analyses of variance of within-plot standard deviations for plant height and days to midbloom, 1969

Source of variation	Degrees of freedom	Mean squares: Plant height	Mean squares: Days to midbloom
Replicates	1	1.88	4.02**
Entries	87	18.37**	0.84**
Fertile singles vs three-ways	1	87.12**	4.68**
Hybrids vs parents	1	63.48*	0.32
Sterile singles vs (fertile singles + three-ways)	1	164.73**	7.48**
Among parents	11	13.71	0.62
Among A-lines	3	28.62*	0.87
Among B-lines	3	12.09	0.43
Among R-lines	3	7.83	0.66
A vs B-lines	1	1.06	0.59
(A+B-lines) vs R-lines	1	4.15	0.38
Among sterile single-crosses	11	5.74	1.26**
Reciprocals	6	3.75	1.35*
g.c.a.	3	13.10	1.39*
s.c.a.	2	0.69	0.78
Among fertile single-crosses	15	20.63*	0.79
g.c.a. (males)	3	27.68*	0.68
g.c.a. (females)	3	4.22	0.97
s.c.a.	9	23.75*	0.77
Among three-way crosses	47	16.34*	0.66
R-lines	3	27.68*	2.55**
Sterile single-crosses	11	13.32	0.87
Reciprocals	6	5.25	0.31
g.c.a.	3	35.83*	0.38
s.c.a.	2	3.75	3.27**
Sterile singles x R-lines	33	16.32*	0.41
Reciprocals x R-lines	18	21.77**	0.46
g.c.a. x R-lines	9	15.53	0.27
s.c.a. x R-lines	6	1.13	0.49
Error (reps x entries)	87	9.40	0.46
Total	175		

Table 71. Analyses of variance of within-plot standard deviations for plant height and days to midbloom, 1970

Source of variation	Degrees of freedom	Mean squares: Plant height	Mean squares: Days to midbloom
Replicates	1	16.30	3.41**
Entries	87	11.02**	0.74**
Fertile singles vs three-ways	1	67.84**	6.01**
Hybrids vs parents	1	11.31	0.00
Sterile singles vs (fertile singles + three-ways)	1	14.69	1.29
Among parents	11	8.30	0.23
Among A-lines	3	9.79	0.05
Among B-lines	3	11.75	0.43
Among R-lines	3	8.65	0.19
A vs B-lines	1	0.18	0.55
(A+B-lines) vs R-lines	1	0.56	0.00
Among sterile single-crosses	11	9.53	1.42**
Reciprocals	6	11.41	1.90**
g.c.a.	3	11.20	1.11
s.c.a.	2	1.38	0.45
Among fertile single-crosses	15	3.06	0.29
g.c.a. (males)	3	0.81	0.45
g.c.a. (females	3	1.80	0.05
s.c.a.	9	4.23	0.31
Among three-way crosses	47	13.22**	0.76**
R-lines	3	31.84**	1.73**
Sterile single-crosses	11	11.79*	1.04**
Reciprocals	6	1.60	0.71
g.c.a.	3	30.01**	0.19
s.c.a.	2	15.03	3.31**
Sterile singles x R-lines	33	12.01**	0.58
Reciprocals x R-lines	18	14.72**	0.44
g.c.a. x R-lines	9	4.75	0.89*
s.c.a. x R-lines	6	14.74*	0.55
Error (reps x entries)	87	6.02	0.42
Total	175		

Table 72. Analyses of variance of within-plot standard deviations for grain yield and yield components, 1969

Source of variation	Degrees of freedom	Mean squares			
		Grain yield	100-seed weight	Heads/ plant	Seeds/ head
Replicates	1	447.05	0.005	0.118*	21650
Entries	87	149.73	0.017**	0.034*	20569
Fertile singles vs three-ways	1	64.11	0.002	0.007	19266
Hybrids vs parents	1	355.51	0.004	0.001	77
Sterile singles vs (fertile singles + three-ways)	1	1295.24	0.141**	0.041	142959*
Among parents	11	136.02	0.011	0.040	33432
Among A-lines	3	78.49	0.012	0.034	36540
Among B-lines	3	201.62	0.002	0.028	55337
Among R-lines	3	73.12	0.011	0.068*	19958
A vs B-lines	1	361.76	0.020	0.012	27822
(A+B-lines) vs R-lines	1	74.80	0.021	0.032	4424
Among sterile single-crosses	11	193.90	0.006	0.016	17199
Reciprocals	6	100.19	0.006	0.004	20552
g.c.a.	3	389.40	0.007	0.031	21146
s.c.a.	2	181.82	0.005	0.029	1220
Among fertile single-crosses	15	93.05	0.020*	0.054**	8633
g.c.a. (males)	3	51.81	0.019	0.081*	4373
g.c.a. (females)	3	89.15	0.027	0.089**	12533
s.c.a.	9	108.09	0.019	0.033	8752

Table 72. (Continued)

Source of variation	Degrees of freedom	Mean squares			
		Grain yield	100-seed weight	Heads/ plant	Seeds/ head
Among three-way crosses	47	134.37	0.018**	0.033*	20006
R-lines	3	171.67	0.058**	0.036	27939
Sterile single-crosses	11	149.39	0.027**	0.033	16765
Reciprocals	6	70.07	0.010	0.017	11604
g.c.a.	3	276.41	0.052**	0.059*	17337
s.c.a.	2	196.81	0.043*	0.045	31388
Sterile singles x R-lines	33	125.97	0.011	0.032	20366
Reciprocals x R-lines	18	98.40	0.008	0.037*	268
g.c.a. x R-lines	9	202.01	0.020*	0.034	11970
s.c.a. x R-lines	6	94.63	0.008	0.013	93251**
Error (reps x entries)	87	98.42	0.010	0.021	21211
Total	175				

Table 73. Analyses of variance of within-plot standard deviations for grain yield and yield components, 1970

Source of variation	Degrees of freedom	Mean squares			
		Grain yield	100-seed weight	Heads/ plant	Seeds/ head
Replicates	1	104.32	0.004	0.020	39121
Entries	87	109.36	0.012	0.049	24852
Fertile singles vs three-ways	1	49.81	0.114**	0.221*	442
Hybrids vs parents	1	1274.34**	0.025	0.014	157518*
Sterile singles vs (fertile singles + three-ways)	1	327.72	0.000	0.224*	103773
Among parents	11	28.14	0.014	0.016	30733
Among A-lines	3	23.46	0.008	0.014	14947
Among B-lines	3	32.51	0.032*	0.033	30374
Among R-lines	3	22.43	0.004	0.006	51812
A vs B-lines	1	73.96	0.000	0.004	33856
(A+B-lines) vs R-lines	1	0.33	0.021	0.009	12805
Among sterile single-crosses	11	84.45	0.006	0.046	10938
Reciprocals	6	112.31	0.005	0.045	15545
g.c.a.	3	69.15	0.003	0.048	7917
s.c.a.	2	23.79	0.013	0.043	1651
Among fertile single-crosses	15	108.10	0.006	0.036	20816
g.c.a. (males)	3	241.96	0.008	0.039	22149
g.c.a. (females)	3	103.88	0.001	0.031	21553
s.c.a.	9	64.89	0.006	0.036	20126

Table 73. (Continued)

Source of variation	Degrees of freedom	Mean squares			
		Grain yield	100-seed weight	Heads/ plant	Seeds/ head
Among three-way crosses	47	106.37	0.012	0.055	24026
R-lines	3	241.42	0.046**	0.067	21980
Sterile single-crosses	11	114.44	0.009	0.085	27800
Reciprocals	6	109.55	0.012	0.052	33385
g.c.a.	3	105.84	0.008	0.109*	34968
s.c.a.	2	142.02	0.004	0.148*	290
Sterile singles x R-lines	33	91.41	0.010	0.044	22954
Reciprocals x R-lines	18	71.78	0.009	0.035	24647
g.c.a. x R-lines	9	166.74	0.013	0.085*	23818
s.c.a. x R-lines	6	37.28	0.008	0.012	16579
Error (reps x entries)	87	121.36	0.009	0.038	36019
Total	175				

Table 74. Means of sterile single-crosses for plant height and days to midbloom from combined 1969 and 1970 experiments

Hybrid	Plant height (cm)	Days to midbloom
A Kafir 60 x B Martin	116.4	77.9
A Martin x B Kafir 60	117.1	76.8
A Kafir 60 x B Wheatland	107.4	77.7
A Wheatland x B Kafir 60	103.7	79.6
A Kafir 60 x B Redlan	118.0	79.2
A Redlan x B Kafir 60	120.7	79.7
A Martin x B Wheatland	104.3	80.7
A Wheatland x B Martin	108.7	80.9
A Martin x B Redlan	115.5	78.3
A Redlan x B Martin	124.4	81.2
A Wheatland x B Redlan	106.2	80.0
A Redlan x B Wheatland	108.7	81.2

Table 75. Mean within-plot standard deviations of fertile single-crosses for plant height and days to midbloom from 1969 experiment

Hybrid	Plant height (cm)	Days to midbloom
A Kafir 60 x R Tx 7078	6.85	1.90
x R Redbine 60	6.75	2.90
x R Plainsman	5.75	1.30
x R Caprock	16.85	2.20
A Martin x R Tx 7078	5.65	2.25
x R Redbine 60	13.50	3.50
x R Plainsman	7.60	3.10
x R Caprock	9.35	1.85
A Wheatland x R Tx 7078	6.00	1.95
x R Redbine 60	7.40	2.25
x R Plainsman	7.00	2.55
x R Caprock	10.40	2.50
A Redlan x R Tx 7078	7.70	1.70
x R Redbine 60	8.55	1.45
x R Plainsman	13.35	2.80
x R Caprock	7.65	1.50

Table 76. Mean within-plot standard deviations of fertile single-crosses for plant height and days to midbloom from 1970 experiment

Hybrid	Plant height (cm)	Days to midbloom
A Kafir 60 x R Tx 7078	6.30	2.10
x R Redbine 60	5.95	1.65
x R Plainsman	5.60	1.80
x R Caprock	7.95	1.80
A Martin x R Tx 7078	5.45	2.15
x R Redbine 60	8.00	1.80
x R Plainsman	5.80	2.50
x R Caprock	3.75	0.95
A Wheatland x R Tx 7078	6.35	1.95
x R Redbine 60	4.60	2.25
x R Plainsman	5.05	1.40
x R Caprock	6.35	1.30
A Redlan x R Tx 7078	5.05	1.55
x R Redbine 60	7.55	1.80
x R Plainsman	7.75	1.80
x R Caprock	5.70	1.65

Table 77. Mean within-plot standard deviations of three-way hybrids for plant height and days to midbloom from 1969 experiment

Hybrid	Plant height (cm)	Days to midbloom
(AK x BM) x Tx 7078	11.8	2.7
(AM x BK) x Tx 7078	9.6	2.3
(AK x BM) x Redbine 60	9.3	2.3
(AM x BK) x Redbine 60	14.2	2.5
(AK x BM) x Plainsman	10.8	1.7
(AM x BK) x Plainsman	8.7	2.2
(AK x BM) x Caprock	10.4	2.8
(AM x BK) x Caprock	11.1	1.4
(AK x BW) x Tx 7078	13.1	2.8
(AW x BK) x Tx 7078	8.8	3.1
(AK x BW) x Redbine 60	8.7	3.2
(AW x BK) x Redbine 60	12.1	2.5
(AK x BW) x Plainsman	9.2	2.6
(AW x BK) x Plainsman	11.8	2.1
(AK x BW) x Caprock	9.5	2.7
(AW x BK) x Caprock	12.5	2.8
(AK x BR) x Tx 7078	10.4	3.1
(AR x BK) x Tx 7078	11.2	2.4
(AK x BR) x Redbine 60	16.5	3.3
(AR x BK) x Redbine 60	18.9	3.7
(AK x BR) x Plainsman	12.7	2.0
(AR x BK) x Plainsman	9.9	2.0
(AK x BR) x Caprock	10.5	2.4
(AR x BK) x Caprock	12.9	2.6
(AM x BW) x Tx 7078	9.7	2.3
(AW x BM) x Tx 7078	8.3	2.8
(AM x BW) x Redbine 60	7.9	3.7
(AW x BM) x Redbine 60	7.7	3.4
(AM x BW) x Plainsman	7.4	2.6
(AW x BM) x Plainsman	11.9	2.3
(AM x BW) x Caprock	9.5	3.5
(AW x BM) x Caprock	11.8	3.4

AK = A Kafir 60	BK = B Kafir 60
AM = A Martin	BM = B Martin
AW = A Wheatland	BW = B Wheatland
AR = A Redlan	BR = B Redlan

Table 77. (Continued)

Hybrid	Plant height (cm)	Days to midbloom
(AM x BR) x Tx 7078	8.3	2.9
(AR x BM) x Tx 7078	10.6	3.0
(AM x BR) x Redbine 60	19.6	2.6
(AR x BM) x Redbine 60	7.2	3.4
(AM x BR) x Plainsman	7.1	2.8
(AR x BM) x Plainsman	9.7	2.1
(AM x BR) x Caprock	7.9	3.5
(AR x BM) x Caprock	14.1	3.1
(AW x BR) x Tx 7078	11.3	3.1
(AR x BW) x Tx 7078	7.8	1.7
(AW x BR) x Redbine 60	7.8	2.0
(AR x BW) x Redbine 60	16.1	2.8
(AW x BR) x Plainsman	8.9	2.5
(AR x BW) x Plainsman	8.9	1.4
(AW x BR) x Caprock	8.2	3.0
(AR x BW) x Caprock	11.5	2.3

Table 78. Mean within-plot standard deviations of three-way hybrids for plant height and days to midbloom from 1970 experiment

Hybrid	Plant height (cm)	Days to midbloom
(AK x BM) x Tx 7078	7.5	2.7
(AM x BK) x Tx 7078	12.9	2.1
(AK x BM) x Redbine 60	8.9	3.1
(AM x BK) x Redbine 60	9.1	1.4
(AK x BM) x Plainsman	5.7	1.5
(AM x BK) x Plainsman	6.6	1.5
(AK x BM) x Caprock	11.9	1.4
(AM x BK) x Caprock	8.0	1.6
(AK x BW) x Tx 7078	9.7	2.4
(AW x BK) x Tx 7078	9.4	2.3
(AK x BW) x Redbine 60	13.3	3.0
(AW x BK) x Redbine 60	7.6	2.5
(AK x BW) x Plainsman	6.8	2.1
(AW x BK) x Plainsman	7.8	2.7
(AK x BW) x Caprock	7.4	2.1
(AW x BK) x Caprock	8.7	2.1
(AK x BR) x Tx 7078	6.0	2.3
(AR x BK) x Tx 7078	9.5	2.6
(AK x BR) x Redbine 60	8.3	2.6
(AR x BK) x Redbine 60	8.8	2.8
(AK x BR) x Plainsman	5.6	2.2
(AR x BK) x Plainsman	9.8	1.8
(AK x BR) x Caprock	12.7	2.5
(AR x BK) x Caprock	5.6	4.1
(AM x BW) x Tx 7078	5.1	2.6
(AW x BM) x Tx 7078	6.2	2.4
(AM x BW) x Redbine 60	5.3	2.6
(AW x BM) x Redbine 60	5.3	2.5
(AM x BW) x Plainsman	4.9	2.2
(AW x BM) x Plainsman	4.6	1.7
(AM x BW) x Caprock	7.2	2.1
(AW x BM) x Caprock	6.1	2.7

AK = A Kafir	BK = B Kafir 60
AM = A Martin	BM = B Martin
AW = A Wheatland	BW = B Wheatland
AR = A Redlan	BR = B Redlan

Table 78. (Continued)

Hybrid	Plant height (cm)	Days to midbloom
(AM x BR) x Tx 7078	7.4	2.7
(AR x BM) x Tx 7078	10.7	4.1
(AM x BR) x Redbine 60	12.6	1.9
(AR x BM) x Redbine 60	6.6	2.7
(AM x BR) x Plainsman	5.3	1.8
(AR x BM) x Plainsman	4.3	1.9
(AM x BR) x Caprock	5.1	2.0
(AR x BM) x Caprock	5.6	2.1
(AW x BR) x Tx 7078	6.2	1.8
(AR x BW) x Tx 7078	4.8	1.8
(AW x BR) x Redbine 60	5.8	1.8
(AR x BW) x Redbine 60	12.2	1.6
(AW x BR) x Plainsman	4.6	1.6
(AR x BW) x Plainsman	6.7	1.6
(AW x BR) x Caprock	12.5	3.0
(AR x BW) x Caprock	8.5	1.9